The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME XV

OXFORD
AT THE CLARENDON PRESS
LONDON: GEOFFREY CUMBERLEGE
1947

EDITORIAL BOARD

SIR E. J. RUSSELL, Campsfield Wood, Woodstock, Oxfordshire (*Chairman*).

W. V. BLEWETT, Agricultural Research Station, Jealott's Hill, Bracknell, Berks.

G. F. CLAY, Colonial Office, 9 Bridge Street, London, S.W. 1.

DR. E. M. CROWTHER, Rothamsted Experimental Station, Harpenden, Herts.

SIR F. L. ENGLEDOW, School of Agriculture, Cambridge.

SIR H. A. TEMPANY, 7 North End House, Fitzjames Avenue, London, N. 16.

PROF. J. A. SCOTT WATSON, Ministry of Agriculture and Fisheries, Bickenhall Mansions, London, W. 1.

(*The above constitute the Executive Committee*)

DR. E. S. ARCHIBALD, Central Experimental Farm, Ottawa, Canada.

PROF. G. E. BLACKMAN, Dept. of Agriculture, Oxford.

J. M. CAIE, 2 Cobden Road, Edinburgh, 9.

PROF. E. E. CHESSMAN, Horticultural Research Station, East Malling, Kent.

DR. C. CROWTHER, c/o Harper-Adams Agricultural College, Newport, Salop.

DR. D. P. CUTHBERTSON, Rowett Research Institute, Aberdeen.

DR. W. DAVIES, Grassland Improvement Station, Drayton, Stratford-on-Avon.

DR. I. ELAZARI-VOLCANI, Agricultural Experiment Station, Rehovot, Palestine.

SIR G. EVANS, Royal Botanic Gardens, Kew, Surrey.

DR. J. HAMMOND, School of Agriculture, Cambridge.

A. G. G. HILL, East African Agricultural Research Institute, Tanganyika.

DR. P. S. HUDSON, Imperial Bureau of Plant Breeding and Genetics, Cambridge.

G. V. JACKS, Imperial Bureau of Soil Science, Harpenden.

DR. T. J. JENKIN, Welsh Plant Breeding Station, Aberystwyth.

DR. B. A. KEEN, Rothamsted Experimental Station, Harpenden.

PROF. J. N. MUKHERJEE, Indian Agricultural Research Institute, New Delhi, India.

DR. R. NEWTON, University of Alberta, Edmonton, Canada.

DR. R. V. NORRIS, Tea Research Institute, Talawakelle, Ceylon.

DR. W. G. OGG, Rothamsted Experimental Station, Harpenden, Herts.

H. J. PAGE, Imperial College of Tropical Agriculture, Trinidad.

DR. I. B. POLE EVANS, P.O., Irene, Transvaal, South Africa.

DR. J. A. PRESCOTT, Waite Agricultural Research Institute, Glen Osmond, S. Australia.

SIR T. RIGG, Cawthron Institute, Nelson, New Zealand.

SIR H. STEWART, British Middle East Office, 10 Sharia Tolumbat, Cairo, Egypt.

SIR F. A. STOCKDALE, The Colonial Office, London.

DR. H. H. STOREY, Colonial Office, 9 Bridge Street, London, S.W. 1.

PROF. S. M. WADHAM, School of Agriculture, The University, Melbourne.

PROF. STEPHEN WATSON, Dept. of Agriculture, Edinburgh University.

DR. NORMAN C. WRIGHT, Hannah Dairy Research Institute, Kirkhill, Ayr.

Secretary and General Editor

DR. E. H. TRIPP, c/o Rothamsted Experimental Station, Harpenden, Herts.

CONTENTS

Number 57

J. E. VAN DER PLANK: Some Climatic Factors determining High Yields of Potatoes. Part II. The Potato at Low Latitudes and High Altitudes 1

J. GLOVER: Environment and the Growth of the Potato (*Solanum tuberosum*) in Tropical East Africa 9

B. M. BOYNS: Sudanese Cattle as Milk Producers. With Plates 1 and 2 27

J. A. THORBURN: The Control of Ectoparasitic Infestations of Farm Stock with 'Gammexane', with special reference to the Arsenic-resistant Blue Tick 42

J. M. ARMSTRONG and T. M. STEVENSON: The Effects of Continuous Line Selection in Triticum-Agropyron Hybrids. With Plates 3 and 4 51

Number 58

A. S. THOMAS: The Cultivation and Selection of Robusta Coffee in Uganda. With Plates 5 and 6 65

T. M. STEVENSON and J. L. BOLTON: An Evaluation of the Self-tripping Character in Breeding for Improved Seed-yield in Alfalfa 82

R. S. YOUNG and A. GOLLEDGE: Mineral Composition of Mine-compound Foodstuffs in Northern Rhodesia . . 89

C. A. THOROLD: A Study of Yields, Preparation Out-turns, and Quality in Arabica Coffee. Pt. I. Yields . . . 96

D. J. FINNEY: The Construction of Confounding Arrangements. 107

A. G. DAVIS: Lucerne Growing 113

H. P. DONALD and A. A. EL ITRIBY: The Age-distribution of Pedigree Cattle and Factors affecting it 119

E. G. HALLSWORTH and V. M. LEWIS: Some Factors affecting the Ascorbic-acid Content of Tomatoes in New South Wales. 132

Number 59

JOSEPH EDWARDS: Artificial Insemination in Cattle: A Review 149

F. R. TUBBS: The Effect of Cultivation on the Growth of Young Tea 160

C. A. THOROLD: A Study of Yields, Preparation Out-turns, and Quality in Arabica Coffee. Pt. II. Preparation Out-turns and Quality 167

R. J. LATHBURY: The Development of Wheat Varieties in Kenya 177

D. MEREDITH: A Comparison of Inorganic Fertilizers and Compost on Natural Pastures in South Africa 189

L. J. S. LITTLEJOHN: Experiments with Potatoes in Cyprus . 195

J. M. DENT: Some Soil Problems of Empoldered Rice Lands in Sierra Leone 206

Number 60

SIR FRANK WARE: Indian Cattle in the United States of America. With Plate 7 213

J. G. HAWKES: The Photoperiodic Reactions of Potato Bolters. With Plate 8 216

JANE BROADFOOT: Preliminary Experiments on the Protection of Cut Sets of Potato from Infection with Penicillium . 227

BRYNMOR THOMAS and N. TRINDER: The Ash Components of Some Moorland Plants 237

HAROLD H. MANN: Pulse Grain Crops in the Middle East . 249

O. DE VRIES and P. BRUIN: Liming Problems on Light Soils in the Netherlands 260

SOME CLIMATIC FACTORS DETERMINING HIGH YIELDS OF POTATOES

PART II. THE POTATO AT LOW LATITUDES AND HIGH ALTITUDES

J. E. VAN DER PLANK

(*Division of Botany and Plant Pathology, Union of South Africa*)

A CLIMATE resembling that of the Andean potato-centre in temperature is found in many elevated places in tropical Africa and the Rhodesias [10]. In S. Africa the resemblance is close enough for practical purposes in the Highveld of the Transvaal, the eastern Free State, and Basutoland, and in the Highland Sourveld of the NE. and E. Transvaal, Natal, and eastern Cape Province, at an altitude of about 5,000 ft. or more. Here the mid-summer temperature is like that of Aroostook County, Maine, but the growing-season is twice as long. There is also a sufficiently close resemblance in parts of southern Asia: in the hills of Assam, for example, or in SW. China round Tengueh, which is so like the Transvaal Highveld in latitude, altitude, and seasonal temperatures. In these regions the climate approaches the ancestral and therefore (one may argue) the ideal climate.

The yields per acre in the Andes potato-centre itself are difficult to ascertain. It seems from Hawkes' account [11] that high average yields have been found where the plants are kept healthy and the best-yielding varieties are grown. Moreau [12] states that, given good husbandry, excellent yields can be raised in tropical Africa. In S. Africa in 1943 it was decided to check the yields from seed produced in bulk by the State as a war-time measure. Three farms on the Transvaal Highveld were chosen, on the grounds that the owners were the largest three buyers of the seed within easy-visiting distance from Pretoria. All were in belts of good fertile soil, but there had been no building-up of fertility in the way which is usual in western Europe. As far as could be ascertained, the cropping-system had been a perpetual rotation of potatoes with maize or teff, without green-manuring or the application of organic manures in appreciable amounts. The seed was planted with a war-time ration of artificial fertilizer, and the crops were cultivated in the usual way without any use of fungicides or insecticides. The treatment was quite normal; in all three instances the fields were over 20 acres and too large for pampering, and in any event the farmers were rather sceptical about the State-grown seed (which was released that year for the first time) and not inclined to give the crops special treatment. In all instances the yield ran over 400 bu. per acre. This would be a good commercial yield anywhere in the world. It was not exceptional, and reports of good yields streamed in from a wide area, and have continued to come in the years since then. On the farms that were visited the yield from the State-grown seed was twice as high as that from locally grown seed; it needed good seed to prove that the Transvaal Highveld and

similar areas were among the centres of the world where high commercial yields of potatoes could be obtained without undue fuss.

Despite the great advantage of climate at low latitudes and high altitudes, yields are commonly very poor. Some of the reasons, like poor husbandry, are of local significance, and only two more general problems, poor seed and poor or unsuitable varieties, will be discussed here.

Poor seed.—It has often been remarked what poor seed is used in the tropics and sub-tropics. Leaf-roll is rife in S. Africa, and in SW. China Dykstra [13] found that all potatoes were infected with it. Over large areas at low latitudes the potato viruses are far too common. But this is not to say that infection is either universal or inevitable. The study of potato viruses has developed mostly in the temperate zone, and development has consequently been rather one-sided. In N. America and Europe the great centres of seed-production are in the north, and it seems to have been inferred by a process of extrapolation that the tropics and sub-tropics are unfit for growing seed. This is quite against the facts, because good seed can be, and is being, grown. Familiarity only with the seed-areas of Europe and N. America has caused the fact to be overlooked that there are many types of climate in which the aphid-borne viruses can be controlled. In concluding some remarks about cool maritime climates the writer [14] named three of them. This was an under-estimate: there are probably at least five, of which three normally belong to the tropics or sub-tropics. In addition, there are ways and means of growing good seed even where the climate is not very suitable. A discussion of seed-growing in the tropics and sub-tropics would be quite out of place here, but just to prove what can be done reference might be made to the Basuto, an unlettered African nation whose accomplishment of keeping potatoes healthy makes the publicized achievements in Ireland look trivial.

On the evidence, there is no reason why healthy seed should not become as general at low latitudes as at high. In parts of the tropics backward peasant populations and inadequate transport may preclude the establishment of a specialized seed industry, which is a feature of northerly latitudes. Some adjustment may be needed, but that implies no difficulty. There are features about the tropics which might compensate for the lack of much of what elsewhere is considered essential.

Unsuitable varieties.—There does not seem to have been any conscious effort to breed potatoes on the Andes [15] and many of the Andean varieties seem remarkably poor. In S. Africa, 13 Andean varieties were compared in the field with Up-to-Date. Their choice was quite random: they were the first 13 cultivated tetraploid varieties to be available. Some were fairly good but 7 (E.P.C. 369, 501, 588, 595, 1090, 1094, and 1144) were poor. In a summer planting their average yield was about 7 per cent. of that of Up-to-Date; in winter it was about 16 per cent. In short days and long they were bad. It is not suggested that they are typical of what is grown on the Andes—a collection must include the atypical—but their existence suggests that much is planted which is unfit for planting.

Outside S. America the varieties commonly grown are those bred in Europe or N. America. They embody the achievements of generations of great breeders in these countries, and have many qualities to commend them at low latitudes. Nevertheless, they do not seem really at home, and probably do not make adequate use of the climatic advantages which the tropics and sub-tropics possess. In the present state of our knowledge it is not possible to make a list of all the useful qualities which were present in the ancestral Andean potatoes but have been shed in the course of breeding in Europe and N. America. Two examples are given —lateness and long dormancy—which fit in with the theme of this paper. (Another will be obvious from the discussion in the next section.) At low latitudes European and N. American varieties mature very rapidly. This matter has been discussed by Moreau [12], who showed that the growing-period of different varieties at low latitudes was 25 to 54 per cent. shorter than in Britain. On the Transvaal Highveld, for example, Up-to-Date behaves like an early variety and matures within 120 days; and the writer knows of no European or N. American variety which can use much more than half the available growing-season. The hastening of maturity is probably a photoperiodic process which entails its own compensation in the form of a greatly accelerated rate of tuber-production. Nevertheless, the waste of half the growing-season must reduce yield to an extent that is at present impossible to compute. Coupled with a short growing-season is a long dormant period. This is a general problem throughout the tropics and sub-tropics, wherever only one generation is grown a year, which is the common practice. It is a problem which has been given special recognition in hot areas, like the plains of India, and it is apt to be overlooked that it is universal at low latitudes even in the coolest climates. In the absence of any seasonal change of temperature in equatorial countries the off-season is as warm as the growing-season and does not give that check to sprouting and senility which winter at high latitudes gives. One need only imagine keeping an early variety the whole year round at the temperature of an English or Scottish summer to appreciate the problem. In the sub-tropics the difficulty is not so great, but it nevertheless exists wherever the latitude is low enough to prevent a great contrast in temperature between summer and winter.

There should be no difficulty about overcoming these difficulties by breeding. Appropriate qualities exist in many Andean varieties. It remains to use them as a foundation for developing new varieties which would also have those properties that are now considered desirable at any latitude, like high productivity and immunity or resistance to fungoid, virus, and bacterial diseases.

Length of Day

It is generally agreed now that the cultivation of the potato began on the Andes where the days are short throughout the year and where potatoes are specially adapted to short-day conditions. The question arises to what extent the modern domestic potato has changed in its photoperiodic reactions. Because cultivation is now most extensive in

the north temperate zone and the potato has to grow during long summer days, the general opinion seems to be that the crop has been changed by selection and breeding and now requires long days for the best results. Bald [16] was probably expressing this feeling when he stated that the modern potato was a long-day plant and that yields are reduced by 25 to 50 per cent. by short days. Moreau [12] and Rayner [17] have replied with evidence to show that short days are not so bad as they are made out to be, even for modern domestic varieties. But the contention in this paper is quite different: far from taking a defensive attitude about short days, it is maintained that the claims made for long days arise from a confusion of the issues, and that it is only in short days that the highest efficiency can be expected from the potato. Ancestry has, it seems, left its mark, and all the breeding and selection of the past has not been successful in altering the primitive preference for short days.

Three results have consistently emerged from experiments with potatoes under different lengths of day. Short days hasten maturity, reduce the growth of the haulms, and increase the efficiency of tuber-formation in the sense that a greater weight of tubers develops from unit leaf-area or unit weight of haulm in unit time. These results are obtained not only for short-day, but also long-day varieties, that is, for varieties which give the greatest yield per plant in long days. The literature has been reviewed by Driver and Hawkes [4] and need not be entered into here. A short-day variety is therefore one in which the gain of efficiency in short days outweighs, and a long-day variety one in which the gain in efficiency does not outweigh, the reduction in growing-period and bulk of haulm. In brief, the term 'long-day potato variety' is a euphemism for a variety which in certain circumstances is a short-lived and undersized dwarf, and cannot make adequate use of the growing-season or the fertility and moisture available. There is no hint of special merit in long days; and provided that the variety makes enough growth and lives long enough to make proper use of the circumstances, all the evidence goes to show that short days will give the best results. Ability to grow adequately in short days exists not uncommonly among tetraploid varieties. If it is absent in the modern domestic varieties of Europe and N. America, it is because they have been selected for size in conditions almost optimal for the growth of haulms; and what has been mistaken for merit in long days is simply the ineptness of modern varieties for short days.

Although the efficiency of short days is of most value at low latitudes, it can be used in cool maritime climates. These climates are characterized by a long frost-free autumn, partly because the season is long and partly because the temperature-seasons lag far behind the solar seasons. Up till the time that blight reached Europe the autumn seems to have been properly exploited, but nowadays a liking for early maincrop varieties and the destruction of haulms by, or as a measure against, blight have largely wasted one of the main benefits which a maritime influence gives at high latitudes. For it must be recognized that a long frost-free autumn is probably the most valuable point of difference between maritime and continental climates at high latitudes; the

extra growing-period in spring is not so long and is without special photoperiodic value, whilst other differences like higher atmospheric humidity, weaker radiation, and smaller daily ranges of temperature are probably points against maritime climates. It is not suggested that there would be any value in prolonging the life of a blighted and senescent crop into the autumn, nor is it suggested that crops should be planted later, which would be unsound in theory and flatly against experimental findings. We are criticizing not the time of planting but modern varieties.

It is not known just how long crops should grow in the autumn. That crops in NW. Europe should enter October in full vigour and health seems likely if good use is to be made of the short days, but whether it is worth prolonging growth into the cold, dark days of November, where absence of frost permits it, is another matter. There are indications in the evidence that the efficiency of short days may disappear when temperatures are very low and perhaps also when light is dim, and, moreover, November days may be too short because the case for short days is for days of about 12 hours.

Some comments have recently appeared about yields in the past. Wallace [18] quotes Arthur Young to show that yields in Lincolnshire were higher at the end of the eighteenth century than they are now. In the article 'The Gardeners' Chronicle One Hundred Years Ago' in the *Chronicle* for Nov. 24, 1945, and in subsequent editorial comment in the issue for Jan. 12, 1946, reference is made to the fact that 'the yield of Potatoes has . . . neither increased nor diminished in one hundred years. Yet, during that time, a vast amount of money and time has been spent on soil science, on pest and disease control, on the study of virus infections—part of which may be debited to the Potato—yet the result in regard to the Potato crop, as represented by increased yields, is nil.' The suggestion follows 'that with the exception of the plant-breeder, the scientist could be dispensed with in respect of this crop'. The verdict is questionable. Although pathologists have not been blameless[1] it may yet be shown that the fault lies with modern varieties which fail to make proper use of the autumn.

Discussion

Sir Frank Engledow has suggested that there is a limit to the extent to which plant-breeding can adapt a crop to new or unfavourable climatic conditions. This suggestion can be given a particularly apt test with the potato in relation to the length and temperature of the growing-season and to length of day, because ever since the potato was cultivated at northerly latitudes it has been subjected to conditions differing from those in which it evolved. Yet all the breeding, deliberate or uncon-

[1] In defence of the potato-breeders, it must be said that an average of probably about 1 ton per acre is nowadays lost because of potato virus *X*, which, on evidence the writer has collected, seems to have been absent, or practically absent, from fields in Europe 100 years ago, and has only recently become a nuisance as a result of the lop-sided development of the seed industry. Virus *X* can be controlled by immune varieties, but there are other means of control for which the onus is with pathologists.

scious, in northerly continental climates has failed to make *S. tuberosum* resistant to frost or to heat, and all its history as a summer crop in Europe and N. America has failed to wean it from a physiology which reaches its peak of efficiency only in short days. Admittedly, it has become more tolerant of long days, but that is another matter. We are dealing here with physiological efficiency—the amount of tubers formed in unit time from unit mass of haulm (or unit leaf-area)—and this, so far as our information goes, is at its greatest during short days as universally among modern as among ancestral Andean varieties. But intolerance of long days is not universal among Andean varieties—we speak, of course, of tetraploid varieties, not of species like *S. Juzepczukii*. Some Andean varieties are even 'long-day' plants according to the current definition, which uses only gross yield per plant without reference to haulm growth and longevity, and all that modern European and N. American varieties do is to make more use of a character which was already present in their ancestors.

This brings us to an important qualification: It is useful to debate the possibility of modifying a crop by breeding only in respect of those qualities which are universal in the ancestral forms.

The suggestion of a limit to the possibility of modification by plant-breeding has an important corollary. If it is impossible to change a character that was universally present in ancestral forms, one should then be able to determine from characters that are universal in modern varieties what the ancestral forms were like, and consequently where they grew. For example, if one assumes that ability to form tubers efficiently was of value to the existence and survival of the original potatoes, and that the degree of adaptation of plants to their native surroundings is high, then from the universal way in which efficiency in the modern potato is linked with a long, cool, frost-free growing-season and short days one could infer that the potato arose on low-latitude highlands or mountains, because it is only here that all these conditions are found. Further, from a knowledge of the optimal temperature for tuber-formation one could have determined to within a few thousand feet how high on these mountains the place of origin was situated. With nothing but a knowledge of modern potato varieties and how they behave in Europe and N. America, one would have been in a position to tell an explorer where to look for ancestral types, with the qualification that one could not have told him whether to look in tropical America or tropical Africa, because physiology does not distinguish between the two.

On the premiss of a high degree of adaptation of uncultivated plants to their natural environment, it should be possible to develop a new technique of determining in what circumstances crops arose. This use of plant physiology has not been popular, and Alphonse de Candolle went so far as to say in *The Origin of Cultivated Plants* that physiology is the one branch of botanical science likely to be valueless in deciding questions of origin, which is one of the few bad opinions in that work of genius. One must grant the difficulties of the physiological method, but it has this great advantage which all other methods lack: it needs a

knowledge only of modern varieties. Nothing need be known of history, archaeology, philology, botanical affinities, or geographical botany, on which other methods are based. It would also supplement other methods in a useful way, for whereas physiology could tell us in what sort of habitat the crop arose, it cannot always distinguish between geographical units—we have seen, for example, that it cannot decide whether the potato arose in America or Africa—whilst the other methods are generally more suited to deciding the geographical unit and often give too little information on the nature of the habitat.

What the writer would like to see is a work on the physiology of cultivated plants in relation to their origin. Cultivated plants would be the most apt for this, partly because there would be more assurance of adequate financial support, and partly because plants cultivated out of their natural surroundings—as often happens—are perpetually exposed to a process of modification. A work of this sort would be invaluable to plant-breeders because it would show in what circumstances useful changes can be made by selection, to plant geographers and ecologists because it would show which characters are plastic and easily adaptable to new habitats, and to plant physiologists because it would show to what extent the processes with which they deal are inheritances from the past.

Summary

For high yields the potato needs a growing-season which is long and cool but free from frost. These conditions are likely to be found only in two situations: at low latitudes and high altitudes, as on the Andes, or in maritime climates at high latitudes, as in the other old S. American home of the potato, the island of Chiloe.

NW. Europe has a maritime climate, like Chiloe's, and it is here that the best yields are obtained. But as one passes at high latitudes from a maritime to a continental climate, a cool season becomes increasingly incompatible with a long one. With this incompatibility *S. tuberosum* does not seem able to cope, and the general run of yields in high-latitude continental climates is low.

The use of other species of potato to meet this incompatibility may prove difficult. All the potato species likely to be of value for breeding belong to low latitudes, and may be no better fitted for high-latitude continental countries than *S. tuberosum* itself. On climatic grounds there does not seem much promise of high yields in these countries either by introducing resistance to heat on the one hand, or resistance to frost on the other; for example, where the climate is cool enough in summer to suit the potato, all the resistance of *S. acaule* will not extend the growing-season in autumn to make it compare with that of *S. tuberosum* in cool maritime climates, whilst the use of frost-resistant potatoes in spring will raise difficult problems of agronomy.

Something like the Andean type of climate is found in parts of tropical and sub-tropical Africa and Asia. Good yields have at times been obtained there, but the use of varieties that are poor or unsuited to low latitudes, and the prevalence of virus diseases, have limited productivity.

But all the material needed for the breeding of better varieties seems available, and the chances of controlling virus diseases at low latitudes are much better than is generally realized.

For high yields the potato also needs short days. This is as true of modern 'long-day' varieties as of old Andean types, all of which are more efficient in short days, in the sense that they produce a greater mass of tubers in unit time from unit mass of haulm. This fact has been obscured because modern domestic varieties have been selected for size in conditions that are almost optimal for the growth of haulms, and for growing-season in conditions that delay maturity, and are usually unable to make adequate growth or live long enough in short days to make proper use of the enhanced physiological efficiency.

Long frost-free autumns are characteristic of cool maritime climates, and it is suggested that the failure of most modern varieties to make adequate use of the short days of autumn largely accounts for the failure in Britain to raise yields per acre during the last 100 or 150 years.

These results are discussed in relation to a suggestion that there is a limit to the extent to which plant-breeding can adapt a crop to new climatic circumstances.

REFERENCES

1. J. Bushnell, Minn. Agric. Expt. Stat. 1925, Tech. Bull. No. 34.
2. H. O. Werner, Nebr. Agric. Expt. Stat. 1934, Bull. No. 94; Res. Bull. No. 75.
3. J. W. Smith, U.S. Monthly Weather Rev. 1915, **43**, 222–36.
4. C. M. Driver and J. C. Hawkes, Photoperiodism in the Potato. Imp. Bur. Plant-Breed. & Gen. 1943.
5. P. M. Lombard and B. E. Brown, U.S. Dept. Agric. 1944, Farmers' Bull. No. 1958.
6. T. F. Ritchie, Canadian Dept. Agric. 1940, Publ. No. 483.
7. B. E. Livingston, Physiol. Res., 1916, **1**, 399–420.
8. V. Rasumov, Bull. Appl. Bot., Leningrad, 1935, Ser. 3, **6**, 221–26: Plant Breeding Abst. 1935–36, **6**, 285.
9. J. B. Kincer, in U.S. Yrbk. Agric., 1941, p. 690.
10. R. E. Moreau, Empire J. Expt. Agric., 1944, **12**, 13–20.
11. J. G. Hawkes, Potato-collecting Expeditions in Mexico and South America. Imp. Bur. Plant-Breed. and Gen., 1941.
12. R. E. Moreau, E. Afr. Agric. J., 1944, **9**, 203–12.
13. T. P. Dykstra, Amer. Potato J., 1944, **21**, 123–31.
14. J. E. van der Plank, Nature, 1944, **154**, 644.
15. R. N. Salaman, J. Roy. Hort. Soc., 1937, **62**, 261.
16. J. G. Bald, Counc. Sci. Indust. Res. (Australia), 1941. Pamphlet No. 106.
17. R. W. Rayner, E. Afr. Agric. J., 1945, **11**, 25.
18. J. C. Wallace, Min. Agric. Fish. England, 1941. Bull. No. 94.

(Received May 16, 1946)

ENVIRONMENT AND THE GROWTH OF THE POTATO (*SOLANUM TUBEROSUM*) IN TROPICAL EAST AFRICA

J. GLOVER

(*East African Agricultural Research Institute, Amani, Tanganyika*)

THE potato *S. tuberosum*, which was possibly introduced into east tropical Africa as a subsidiary food crop for Europeans, is now for many Africans an appreciated source of food and for others a cash crop of importance. Though a successful introduction, the yields of tubers have generally been lower than those obtained in temperate zones. Some have suggested that this might be due to the detrimental effect of short day-length and high air and soil temperatures. Moreau [1], in a survey of the climatic background of the commercial potato-growing areas in E. Africa, mainly in the cooler zones above 4,000 ft. on the mountain masses, concluded that 'given good husbandry, excellent crops of *S. tuberosum* can be raised in parts of tropical Africa, even though air and soil temperatures seem unfavourably high. The short days seem to be of no practical importance.' He stresses, however, that his data are scanty.

Little is known of the behaviour of the plant in response to a tropical environment and this has prompted the following ecological studies in more extreme environments at altitudes lower than those of the commercial areas.

Two sites were chosen for the experimental plots. Both were at Lat. 5°·09′ S. One was at approximately 3,000 ft. a.s.l. on the top of a mountain block and at the mouth (wide end) of a narrow steep-sided, funnel-shaped valley opening towards the north; the other, some 15 miles away due east on the plains below, was at an altitude of 600 ft. a.s.l. The initial letters of the African names of the sites are used throughout to distinguish the two areas. Thus the mountain area is referred to as K and the plains area, M. The first two experiments, K1 and M, were made simultaneously in the 'cool season' (June–Aug. 1944) following the long monsoon rains. The third, K2, was made at site K at the beginning of the 'short rains' early in the 'hot season' (Nov. 1944–Jan. 1945). The expectation of rain and the actual amounts received at both sites are shown in Table 1. The italic figures represent the period covered by each experiment.

The soils at both sites are derived from gneiss. Previous analyses of samples taken near the experimental areas had shown them to be low in exchangeable bases. A later partial analysis of samples from the sites confirmed that they are very low in available phosphate. The soil of the mountain plots (K) was a yellow sandy loam of pH 5·2; that of the plains plots (M) was a chocolate-red, heavier loam of pH 6·5. Neither had previously been manured and certainly neither was as rich as the soils on which potatoes are grown in England.

As it is of little value to record the influence of environmental factors on poorly nourished plants, it was decided to conduct the observations

on plots laid out as manurial experiments. Lack of space in the mountain area led to the adoption of single replication 2^5 factorial experiments as described by Yates [2]. The individual plots were approximately 1/50th of an acre; the 32 plots of each experiment therefore covered about 3/5ths of an acre. The manures were farmyard manure (d), nitrogen (n), phosphate (p), potash (k), and lime (l), used singly and in all their combinations. The manurial dressings were applied in the

TABLE 1. *The Expectation of Rainfall from the Cumulative Monthly Averages up to 1943 (from the B.E.A. Met. Ser. Tables 1944), and the Actual Monthly Totals during the Experiments*

Site		Rainfall in mm.									
	No. of years	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
K Expected	14	488	159	83	126	131	164	157	166	67
Actual	(1944–5)	321	176	216	114	160	292	196	106	208
M Expected	7	278	64	25	68	61	..	..	..	..
Actual	(1944)	225	82	80	42	..	..	..	..	..

following amounts per acre: f.y.m. 12 t.; ammonium sulphate 3 cwt.; rock phosphate 4 cwt.; potassium sulphate 2 cwt.; and lime (carbonate) 15 cwt. In an endeavour to follow the development of the tubers, plants were harvested at regular intervals after the 44th day from planting. Each plot was divided into 36 sub-plots of 6 plants each, in the form of a Latin square, and at each harvest date 6 of these sub-plots were dug up. Thus the sample from each treatment at each harvest date consisted of 36 plants. The variety used in all experiments was Kerr's Pink, supplied from ordinary commercial stocks grown in Kenya. The seed potatoes were all of fairly uniform size; their mean weight was 55 gm. and the range measured over a 1 cwt. sample was 52–9 gm.

The recent history and preparation of the plots was as follows:

K. The previous crop was *Derris elliptica*, unmanured. The soil was therefore well broken up when the derris roots were harvested some months before planting the potatoes, and required only hand-hoeing before planting. The second experiment on this site, K2, was planted only some 7 weeks after the first crop of potatoes was removed, so again only hand-hoeing was necessary to remove the weeds.

M. The previous cover was grass, which was cut and removed from the block and its surroundings. As the soil was heavy it was first broken by tractor and later hoed by hand.

In K1 and M the ridges were made parallel to the longest sides of the blocks. In K2 they were made at right angles to the former ridges. The spacing in all experiments was 12 in. between the potatoes in the ridges and 24 in. between ridges. Double guard-rows and columns were left between treatments and were not included in the analysis. The potatoes, which had strong ¼-in. sprouts, were buried 4½ in. below the tops of the ridges. All the manures except the more soluble potash and ammonium compounds were applied about 10 days before planting,

and were spread evenly over the plots. It was intended to 'earth up' the potatoes at least twice during growth, but owing to labour shortage it was done only once, 22 days after planting.

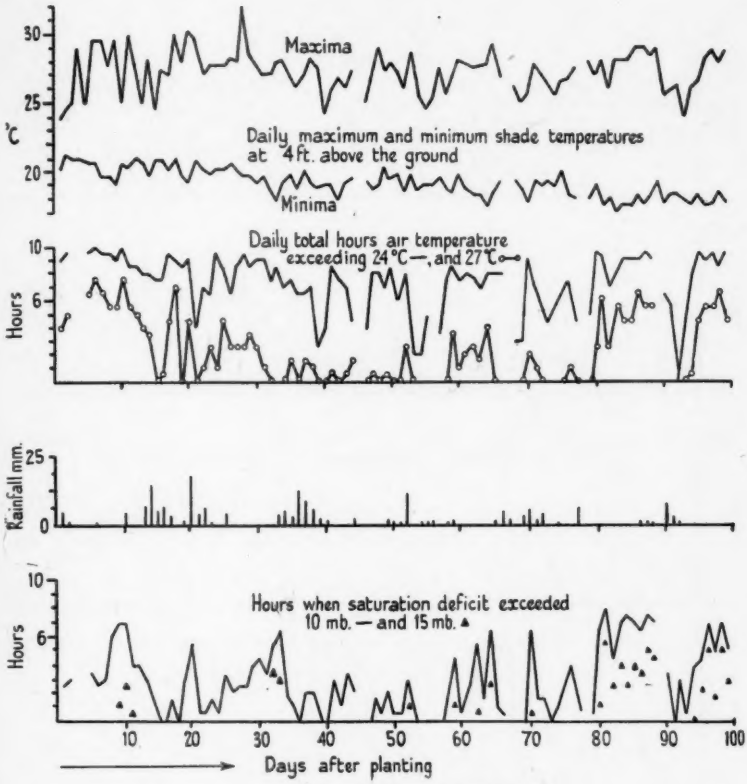


FIG. 1. K1. The climate of K1.

The Measurements of Environmental Factors

It is well known that, when measuring environmental factors in natural surroundings, extremes or means calculated from them may often be misleading. As time of exposure is so important when dealing with factors possibly extreme, the following records of variability of environments throughout the life of the plants are classified as times of exposure to certain arbitrary levels of the factors concerned. The length of day during K1 and M was 11·75 to 11·9 hrs., whilst during K2 it was 12·25 to 12·35 hrs.

The following factors were measured continuously or at regular intervals throughout the experiments at each site.

Rainfall was measured daily by non-recording rain-gauge.

Air temperatures were measured about 4 ft. above the ground immediately beside the plots. From 6 a.m. to 6 p.m. dry-bulb temperatures of Assman psychrometers were read every half-hour. At night (6 p.m.–6 a.m.) thermographs in a meteorological screen provided the data.

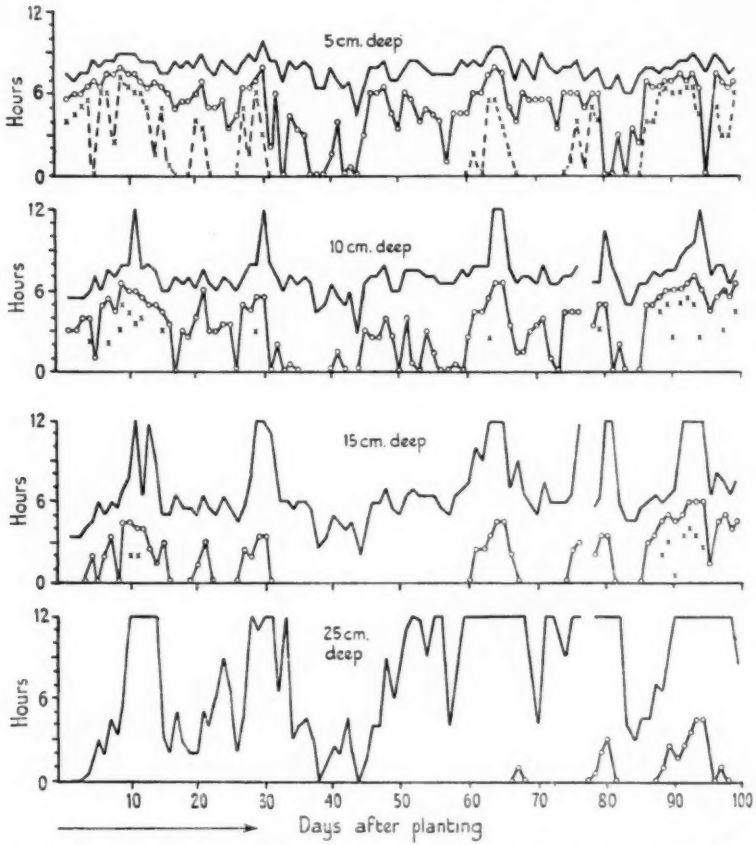


FIG. 2. K1. Daily total hours between 6 a.m. and 6 p.m. when soil temperatures exceeded 21° C. - - - - and 24° C. —

The thermograph records were checked against dry-bulb readings on every third night at 9 p.m., midnight, and 6 a.m., or more often if, as in the mountain area, a cold pocket was likely to develop. For calculating the time of exposure to different levels of temperature, the air temperature during each half-hour period was taken as the mean between the readings at the beginning and end of the period. Thus, if at 6 a.m the temperature was 10° C. and at 6.30 a.m. was 11° C., the temperature for that half-hour would be recorded as 10·5° C. The mean half-hour

values were then distributed into their respective groups (shown in Tables II and III).[1]

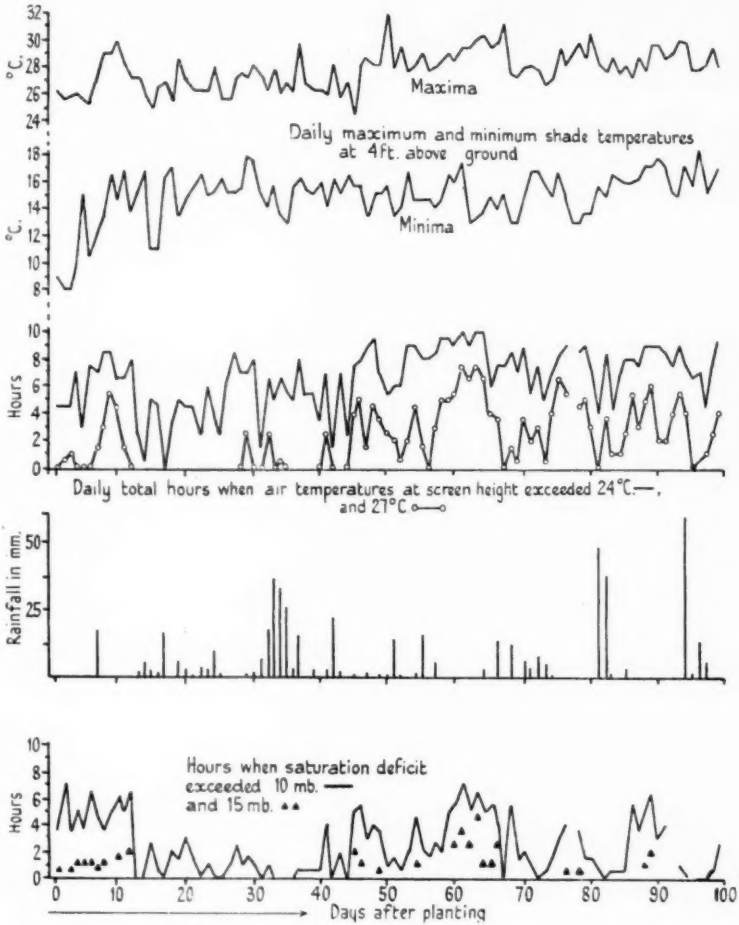

°C.
Maxima
Daily maximum and minimum shade temperatures at 4ft. above ground
°C.
Minima
Hours
Daily total hours when air temperatures at screen height exceeded 24°C.—, and 27°C o—o
Rainfall in mm.
Hours when saturation deficit exceeded 10 mb. —— and 15 mb. ▲▲
Hours
Days after planting

FIG. 3. M. The climate of M.

Soil temperatures were measured at depths of 5, 10, 15, and 25 cm. under bare soil-ridges, and under the plants half-way between the tubers in their ridges. The thermometers were of the bent-glass mercury type. Readings were taken daily every half-hour between 6 a.m. and 6 p.m.,

[1] Owing to lack of space an Appendix with 8 Tables of data (II–IX) has been omitted, but copies can be obtained by applying to the Imperial Bureau of Plant Breeding and Genetics, Cambridge, England. Most of the data in question can be derived from the Figures in the text.—*Edit.*

and at 9 p.m. and midnight every third night or more often. Recording distance-thermometers were used in the bare soil ridges as a check on the readings of the small thermometers. They could not be used under the plants as their bulbs were longer than the distance between the

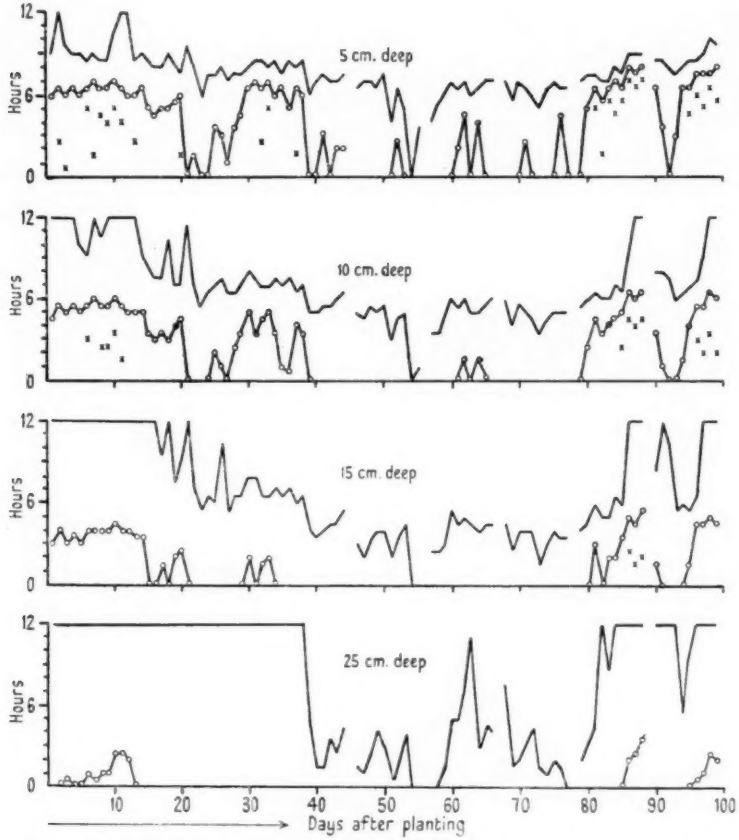


FIG. 4. M. Daily total hours between 6 a.m. and 6 p.m. when soil temperatures exceeded 24° C. —, 27° C. o–o, and 30° C. x–x.

tubers. As the curves drawn by the recording thermometers in bare soil were regular, and as the readings of the smaller thermometers under the plants lay along similar curves, the night temperatures (Table III) were derived from the values given by interpolation in curves similar to those obtained in bare soil, but adjusted to fit the readings at 6 p.m., 9 p.m., midnight, and 6 a.m. The mean half-hour readings were then calculated as described above. Soil temperatures, under high solar radiation, depend to a considerable extent on the shade afforded by the

plants; all those measured under the plants were therefore taken only in well-manured plots, which carried strong healthy plants. Soil temperature also varies considerably with small changes in depth down to 10 cm., so that care was taken to ensure that the thermometers were at

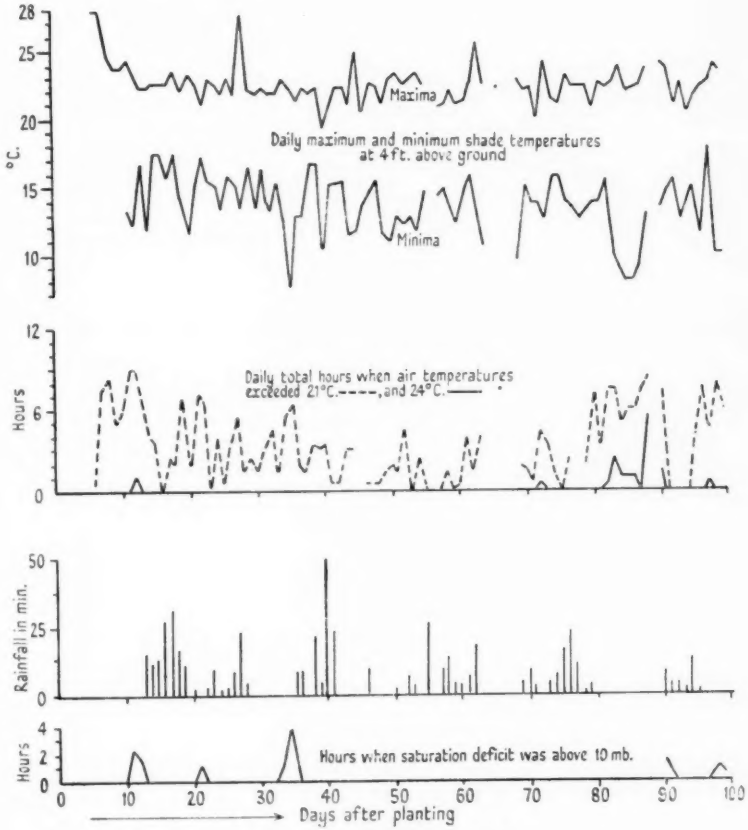


FIG. 5. K2. The climate of K2.

the correct depth. Rain sometimes altered the form of the ridge in the mountain area but this was serious only before the plants provided shade. On one occasion at K after heavy rain about ½ cm. of soil had to be placed on the bare soil drills to replace loss by wash.

Saturation deficit at screen-height was calculated from readings of Assman psychrometers every half-hour as above. A rough check was made against hygrographs and thermographs in the meteorological screens. A series of observations of the saturation-deficit of the air between the ridges of plants, at a height approximately that of the tops

of the ridges, was started 16 days after planting at K2. The readings were taken about three min. after those taken at screen-height.

Solar radiation was measured in one experiment, K2, at one-minute intervals from dawn to dusk throughout the life of the plants. The

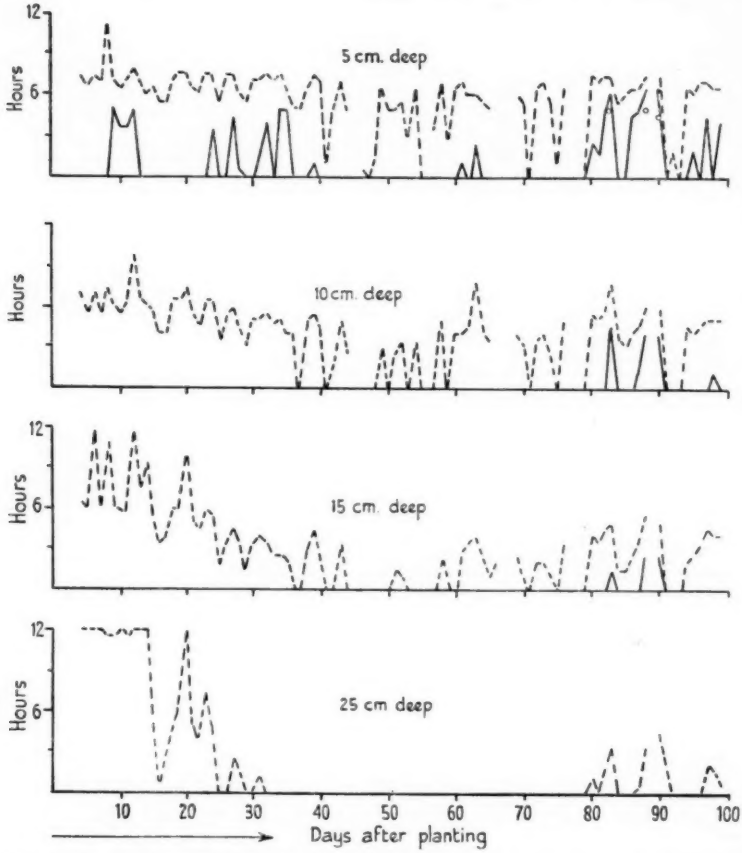


FIG. 6. K2. Daily total hours between 6 a.m. and 6 p.m. when soil temperatures exceeded 24° C. —, 27° C. o–o, and 30° C. x–x.

instrument used was an N.P.L. calibrated Gorczynski solarimeter. In the earlier experiments only a few days' records at each site were obtained as only one instrument was available.

Figs. 1–7 (and Tables II–VI of the Appendix) show the measurements of the various factors. Gaps in the Figures illustrating the march of the factors are due to incomplete records on those days when the recorders were employed to assist with the harvesting or treatment of the crop. Readings of soil thermometers and Assman psychrometers at night were

not started at M until the eleventh day from planting because of the reluctance of the African recorders to visit the plots when man-eating lions were roaming in the neighbourhood.

The mean monthly maximum air temperatures during K1 were 23¼°, 22°, and 22° C., during M 27¾°, 27°, and 27° C., and during K2 26¾°, 28¼°, and 28° C. The mean monthly minimum air temperatures during K1 were 14¾°, 13¼°, and 12½° C., during M 20¼°, 19°, and 18½° C., and during K2 17¼°, 17, and 17¾° C. The salient features of the tables and figures are as follows: All the K1 air temperatures were below the presumed critical level of 27° C. (80° F.), but 18·5 per cent. of the daylight hours were above this in M and 17·2 per cent. of them above it in K2. Further, in K1 only 28 per cent. of the daylight hours and none of the night hours were above 21° C. (70° F.), whilst the corresponding figures for M are 86 and 8 per cent., and for K2 84 and 21 per cent. respectively.

Soil temperatures at 5, 10, 15, and 25 cm. in the drills of the M and K2 experiments were for at least 90 per cent. of the time, night and day, between 21° C. and 30° C., predominance of the zone 24°–27° C. increasing with depth. For at least 99 per cent. of the total time soil temperatures were above the zone 15°–18° C., which Werner [3] says is the region most favourable for tuber production. In K1, soil temperatures were mainly between 15° and 24° C. with increasing predominance of the zone 18°–21° C. with depth. Here, too, much of the total time was spent above the zone 15°–18° C.

The humidity during K1 was high; the saturation deficit was only above 5 millibars, mainly between 5 and 10 mb., for 20 per cent. of the daylight hours. In M and K2 it was lower; 56 per cent. of the daylight hours of M and 54 per cent. of K2 had a saturation-deficit above 5 mb., mainly between 5 and 15 mb. Numerous records of the effect of shade on soil temperatures were obtained (Table IV).

The Measurements of Growth and Yield

The general appearance of the plants was different at the two sites. At K the plants were more lush than at M. When spraying against blight during K1 it was difficult to pass between the drills on the plots treated with f.y.m. and nitrogen without damaging the heavy tops, whilst at M no difficulty of this nature was encountered. The plants at K had one main stem arising directly from the tuber and generally one or sometimes two subsidiary stems or branches. At M there was usually one stem, rarely two. Leaves, too, were larger on the plants at K. In the K2 experiment they appeared to be intermediate in size between those of M and K1, though more like those of M. An attempt was made to measure the differences, but owing to labour shortage and lack of adequate drying-space thorough sampling of the tops was prevented. The results of a few samples (Tables VII and VIII) suggest the reality of the differences observed visually; for on the 78th day from planting the mean areas of single mature leaves of K1 and M were 73 and 56 cm.^{2} respectively, and the mean air-dry weight of the tops was 24 and 10 gm. respectively, whilst on the 89th day from planting the mean length of stem in K1 was 31 cm. and in M only 25 cm.

Field Observations

State of soil at planting. The soil at M was very dry but that at K in both experiments was quite moist below the top ½ cm., which was dry.

Early growth. In K1 and K2 the sprouts appeared above ground 9–12 days after planting. Those at M appeared approximately 10 days later, i.e. 18–22 days after planting.

Misses. None was observed in the experimental plots but there was one in the guard-rows of K1. As no tuber was found in the drill 20 days after planting, it was presumed that an error of planting had been made.

Habit. See Tables 7 and 8 and comments in the text.

Seed-tubers at pickings. After the first picking, 44 days from planting, only 20 per cent. of the seed-tubers showed complete or partial rot. Even at the end of 100 days in the ground about 15 per cent. of the mother tubers was recovered. These were not included in the yield measurements. All of those recovered after the 4th picking in K1 produced sprouts and about 100 were planted in a garden. Their yield at maturity was calculated to be at the rate of 6 t. per acre.

Flowering. During K1 the plants did not flower. During M the plants started to flower on the 42nd day from planting; the flowers, however, though fairly numerous, were shed before maturity. During K2 flowering was profuse; it started on the 36th day from planting and nearly all the flowers were large and well developed. Flowering ended about the 54th day.

Stolons. In all experiments the stolons were rarely longer than 6 in. They were white and unbranched.

Maturity. In general the tops died between the 95th to 100th days from planting. During K2 those plots receiving phosphate only, or phosphate in various combinations with potash and lime, appeared to mature about 5 days earlier than the others.

Death. Blight may have shortened the lives of the plants in all the experiments, but it seemed to be well under control after frequent spraying, which was started when the first symptoms appeared. The plants at M apparently died of drought. They first showed severe wilt during the midday hours between the 75th and 80th days from planting, but during the night they recovered. They died unnaturally early between the 83rd and 90th days from planting. No macroscopic symptoms of disease were present in either haulm or tuber.

Absorption of small tubers. A few small tubers were observed to be reabsorbed when the plants reached maturity. The loss in yield, or number of tubers, due to this was probably negligible when compared with the possible loss of small tubers missed by the pickers.

Size of tubers. Though size is no guide to quality it is noteworthy that more big tubers were produced by the plants in the K2 experiment than in either K1 or M. In the crop from K2 there was a considerable number of tubers between 250 and 380 gm.; in fact one plot, DNPL, yielded over 71 per cent. ware over a 2-in. riddle. The largest tubers from M and K1 were only between 120 and 170 gm.

Possible residual effects of K1 in K2. Yields from the control and most of the single-factor plots (excluding f.y.m.) tended to be lower, and those

from the well-manured plots tended to be higher, than those from similar plots in K1.

Reduction in mean weight of tubers between the penultimate and last pickings at M was almost entirely due to a severe attack of cutworms. Many of the tubers were so badly damaged by them that they were not worth including in the weighings. The attack developed after the plants died.

Diseases. During M and K1 late blight (*Phytophthora infestans*) was apparently the only disease of the living plants. During K2 attacks were recorded of blight, eelworm, tuber moth, and *Fusarium* sp.

The mean overall yields and the effect of manures on the weight and number of tubers at different stages of growth (Table IX) show that the yields at maturity of K1 and K2 were 5·1 and 5·6 t. per acre respectively, as compared with only 3·4 t. per acre 89 days after planting at M (where the plants died of drought before reaching maturity). It also shows that most of the tubers were set early in the life of the plants; in K1 and K2 within 45 days from planting, in M within 36 days from planting, and in all experiments within 35 days after the emergence of the sprouts above ground. Further, the ratio of the mean overall number of tubers carried at maturity to the number of tubers planted shows that the increase during K1 was over eightfold; during K2 between six- and sevenfold, and during M about sixfold.

In all experiments the yields by weight were significantly increased by f.y.m. and nitrogen (ammonium sulphate). The effect of the latter was about half that of the former. In all experiments the number of tubers was significantly increased by f.y.m., and by nitrogen in K1 and M but not in K2. The highest yields from individual plots at the last pickings when the tops were dead, together with the yields of ware and their percentages of the total yields, are shown below in Table 2. Only those plots which yielded 7 t. per acre or more are included. As no plot at M reached this value, only the yield from the best plot is shown.

TABLE 2. *Total Yield and Yield of Ware Potatoes from the best Plots (Tons per acre)*

Expt.	*No. of plots*	*Treatments*	*Average yields*				
			Total yield	*Ware*			
				Above 1½ in.	*Per cent. of total*	*Above 1⅝ in.*	*Per cent. of total*
K1	1	DN	9·1	7·5	82	7·1	78
	3	DNP, NPK, DNL	8·3	6·9	83	6·5	78
	3	DPL, DNKL, DNPKL	7·5	6·1	81	5·6	75
M	1	DN	5·2	4·1	80	3·7	71
K2	1	DNKL	10·6	9·6	90	9·0	85
	3	DN, DNL, DNPL	9·5	8·4	88	7·8	82
	4	DPL, DNPK, DNP, DPKL	7·5	6·5	86	6·0	80

The percentage ware for each plot was calculated on the yields at the final pickings. As an accurate 1⅝-in. riddle was not available the ware was first measured over a 1½-in. riddle. Later the ware from the best plots was measured over a home-made 1⅝-in. riddle.

The effect of the different manurial treatments on the yield of ware was analysed as before. The significant results from all three experiments are shown below in Table 3.

TABLE 3. *The Effect of Manures on the Yield of Ware Potatoes*

Experiments	*K1*	*M*	*K2*
Days from planting	*100*	*100*	*100*
Mean per cent. ware all plots . .	70	71	82
Increase due to D	11	7	8
,, ,, N	..	..	6
,, ,, L	13½	11	14
Significance levels:			
5 per cent.	8	3	6
1 per cent.	11	4	8

Discussion

Yield. The comparison of yields with English yields is difficult as they vary with spacing, soil, treatment, and many other factors. The mean average yields from the above experiments include data from many of the plots which, on an originally very poor soil, received only light manurial dressings and do not therefore form a suitable basis for comparison with English yields. Nevertheless, although the seed-rate was 1·2 t. per acre as against 1 t. per acre in English practice, the yield from the well-manured plots can be compared with English yields since they received treatment such as that recommended by Wallace [4] as good English practice.

The yields of ware above 1½ in. from the well-manured plots at the higher site K, 6·1 to 7·5 t. per acre in the cool, dull season and 6·5 to 9·6 t. per acre in the hot, bright season, compare favourably with the 10·44 t. over 1½ in. recorded for the same variety grown on a heavily-manured light loam at the Midland Agricultural College, Loughborough [5], and are surprisingly good by tropical standards. The percentage ware at K is also similar to that recorded in England during the field trials of the National Institute of Agricultural Botany. There, between 77 and 92 per cent. ware over a 1⅝-in. riddle was recorded between 1935 and 1938, whilst at K over two different seasons the range was 75 to 85 per cent.

F.y.m. at the rate of 12 t. per acre was the most effective of all the manurial treatments. It greatly increased the weight of the crop, the number of tubers, and the percentage of ware. Nitrogen, too, applied at the rate of 3 cwt. of ammonium sulphate per acre gave a heavier crop and a greater number of tubers. In K2 it also gave a significant increase in the percentage ware. Lime had the striking effect of increasing the percentage ware in both experiments, yet it significantly decreased the

number of tubers during K1 and significantly increased the yield by weight in K2. The effects of phosphate and potash were not well marked, though potash increased the number of tubers in K1.

The mean overall yield from the lower site M (3·5 t. per acre) was poor by English standards, but still surprisingly large when it is realized that the plants died before reaching maturity. As in the K experiments, f.y.m. increased the weight of the crop, the number of tubers, and the percentage ware. Nitrogen, too, increased the weight of the crop and the number of tubers, but gave no significant increase of the percentage ware. Lime again greatly increased the percentage ware, whilst phosphate increased both the weight of the crop and the number of tubers.

Photoperiodism, temperature, and yields.—Driver [6] says that 'the optimum temperature for tuber-growth seems to lie between 60° and 65° F., tuberization decreasing rapidly as the temperature rises above 70° F., with a maximum temperature for tuber formation of 80–85° F.'; 'Short days can largely minimize the effects of high temperatures though the yield of the tubers is never so good as under the optimum temperature'; and 'the failure to produce tubers or the very low yields obtained in the tropics may be largely due to the high temperatures prevailing during the growing-season'.

As already shown, the yields from K1 are similar to English yields. Air and soil temperatures during the experiment were not excessively high by the above standards, for, as shown in Fig. 1 (and Tables II, III), day temperatures were rarely above 24° C. (75° F.) and night temperatures rarely above 21° C. (70° F.). In fact, 67 per cent. of the day and 78 per cent. of the night periods were between 15° and 21° C. (59–70° F.), which is not greatly different from that zone regarded as best for optimum growth. The photoperiod, 11·75 to 11·9 hrs., was low. Obviously, then, short days of this length do not appreciably decrease the yield of Kerr's Pink when it is grown at temperatures at or slightly above the optimum.

The yields of the well-manured plots of K2 exceeded those of K1, yet the photoperiod was but 15 to 30 min. longer than in K1, but air and soil temperatures often exceeded those hitherto regarded as optimal. Thus, during K2, mean monthly maximum air temperatures were between 26¾° and 28¼° C. (80–83° F.); 17 per cent. of the daylight hours exceeded 27° C. (80° F.), and 97 per cent. of the day and 81 per cent. of the night periods were above the range 15–18° C., which is considered best for tuber-growth. Soil temperatures, too, were consistently above 18° C., which Richards [7] says is best for later growth. It would seem that if such temperatures as in K2 have a depressing effect, they are not of practical importance when the day-length is between 12·25 and 12·35 hrs.

The most important environmental factor in the experiments seems to have been the fertility of the soil. Good husbandry similar to that practised in England gives good yields even when temperatures are high and day-length short.

Effect of drought.—In the M experiments day-length and temperatures were practically the same as in K2 (Figs. 3–6 and Tables III–VI), but the yields were much lower, the sprouts were slow to emerge above ground

and the plants died early, apparently not from disease. It is highly probable that lack of rain (Table 1) in conjunction with severe drying conditions was responsible for this.

It is well known that the potato requires plenty of soil moisture for its satisfactory growth and that drought limits yields. It might be expected from consideration of Table 1 that, as planting closely followed the end of the 'long rains', the soil would contain sufficient water to start the growth of the already sprouted tubers. However, at M in the year of the experiment, the heavy rains ended rather abruptly on May 10, and from this date to May 29, the date of planting, there was only 22·5 mm. (0·89 in.) of rain, nearly all of it, 19 mm., on one day, the 19th. Even after planting the soil received only 10·5 mm. (0·42 in.) of rain in the first 12 days, and this, as may be seen from Fig. 3, was badly distributed. Further, the breaking up of the soil by tractor cultivation and the hoeing and opening and closing of the ridges occurred after the last heavy rain on May 19. Fresh moist soil must have been exposed after each of these operations. As the air and soil temperatures and saturation deficit during this period were almost certainly similar to those shown in Figs. 3 and 4 for the first 10 days after planting, the evaporation from the exposed surfaces must have been considerable. In fact, as already mentioned, the tubers appeared at the time of planting to be going into very dry soil. Edmundsen [8] found that in one field, when soil temperatures were high, the plants at the lower end with a good supply of water produced an early set of tubers whilst those at the upper end with a poor supply 'did not set tubers until 10 or 12 days later'. The coincidence of these figures with those for the delayed appearance of the sprouts above ground and the delayed set of tubers during M is rather remarkable.

The total rainfall on the plots during the life of the plants was only 204 mm. (8·09 in.) which was moderately well distributed. It fell on 52 days. The approximate times during which rain fell between 6 a.m. and 6 p.m. were recorded and checked roughly by depression of the lines of the thermo-hydrograph. These show that on 49 out of the 52 days much of the rain fell between 9 a.m. and 4 p.m. and only during the heaviest rain did the fall last for more than an hour. Thus most of the light showers were succeeded by the drying conditions induced by high air- and soil-temperatures and moderate saturation-deficit. In fact, it was a common sight to see aqueous vapour rising from the bare soil in the neighbourhood of the plots immediately after the light showers. Apart from interception by the leaves of the plants and subsequent evaporation before reaching the ground, it is doubtful if most of the light falls shown in Fig. 3 penetrated the soil to any effective depth. In fact, when the samples were dug at various stages, the roots near the surface appeared to traverse air-dry soil. It is therefore not surprising that plants grown under such conditions wilted and died before similar plants at K, where the total rainfall was 506 mm. (19·73 in.) on 48 days during K1 and 510 mm. (20·04 in.) on 53 days during K2. In the circumstances it is remarkable that at M the best plot gave 5·2 t. per acre and that the mean overall yield was 3·5 t. per acre.

It would seem, therefore, that good yields might be expected even at the lower site, at least in the cool season, provided that the plants are adequately supplied with water.

Edmundsen [8] has described irrigation experiments with Rural New Yorker No. 2 and Triumph potatoes at Greeley, Colorado, which, according to Stuart [9], was formerly the second largest potato-growing centre of the United States. There, mean maximum air temperatures during 3 months of the growing-season are as high as those of M [10]. Soil temperatures [8], too, at 3½ in. (9 cm.) depth in the drills, are similar to those of M at 10 cm. Further, a 39-year record of rainfall [11] shows that the mean annual precipitation is 12·60 in. (320 mm.), most of which falls in the growing-season.

Thus, during at least 3 months of its life, the potato at Greeley is exposed for some part of the day to extreme environmental conditions resembling those at M; yet commercial and presumably economic crops are grown there when the water-supply is adequate.

Photoperiodism, tuberization, and maturity.—Driver [6], in his summary of the effect of the photoperiod on tuberization, has said that 'Tubers are initiated much earlier under short-day than under long-day conditions, tuberization is more abrupt and maturity is reached much earlier'. There is some slight evidence that these effects of short-day can be distinguished in the foregoing experiments.

In all three experiments most of the measurable tubers were set within 35 days from the appearance of the plants above ground (Table 9). In M there was a big increase in the number of recognizable tubers after the 10-day interval between the 27th and 38th days after emergence above ground (45th to 56th days after planting), and the number of tubers set was apparently not further increased during the life of the plants. In both K experiments the plants died naturally some 90 days after the emergence of the sprouts above ground, and there was no reason to suspect that the life of the M plants would have been longer. Further, since K1 and M were similar in day-length yet widely different in environmental temperatures, any modification of the time of set of tubers or in tuberization might be observed as differences in the size and weight of tubers after the first 35 days from the emergence of sprouts above ground; for only after emergence can the photoperiod be effective. It is unlikely that drought effects would interfere with the comparison, for during this period at both places the rainfall was well distributed and probably adequate. No marked differences were found in either the size or the weight of the tubers after this period. The mean weight of the individual tubers from all the plots of each place was then 10·5 gm. for M and 10·2 gm. for K1, whilst their distribution of size above and below 1 in. diameter, expressed as a percentage of the total number, was for M 35 and 65 per cent. and for K1 42 and 58 per cent., respectively. If only the 16 well-manured plots of both sites are compared, the mean individual tuber weights were 12·8 gm. for M and 12·2 gm. for K1, whilst distribution by size was 40 and 60 per cent. for M and 46 and 54 per cent. for K1.

All this appears to suggest that Driver's conclusion is correct. Unfortunately, the experiments are too few in number to provide conclusive

evidence that temperature may not modify the reaction to the short day-length.

Solar radiation.—The average daily total amount of solar radiation, as measured on the horizontal surface of a Gorczynski solarimeter during the 12·3-hr. day of K2, was similar to that of the average 16·5-hr. day of June in the south of England, since throughout K2 (Table VII) it was 345 gm.-cal. per cm.^{2} (400 kw.-hrs. per dkm.^{2}), whilst in June in England, as measured by a Callendar instrument, it was 419 kw.-hrs. per dkm.^{2} at Rothamsted over the period 1922–4 and 431 kw.-hrs. per dkm.^{2} at South Kensington averaged over the years 1913–20 [12]. Further, the amount

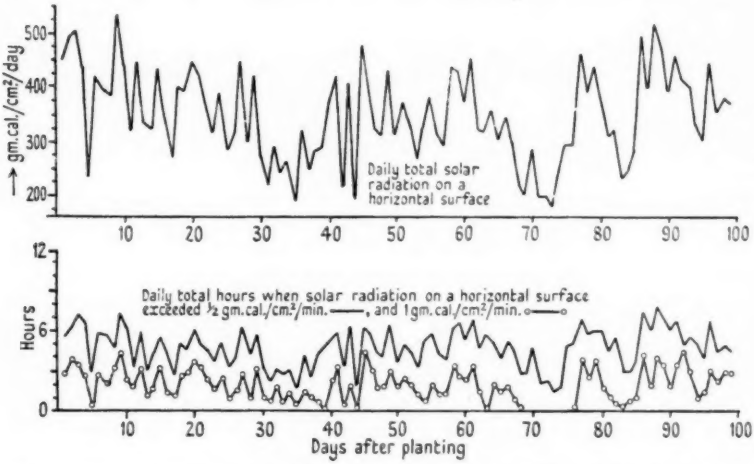


FIG. 7. K2. Measurements of solar radiation on a horizontal surface beside the plots of K2.

of radiation received by the K2 plants during their life above ground was not much less than the average amount plants of the same variety would receive while above ground in the south of England, for the life of Kerr's Pink above ground there is evidently from about June 1 to Sept. 30, and the average total amount of radiation received at South Kensington (1913–20) and Rothamsted (1922–4) during this period was about 42,000 kw.-hrs. per dkm.^{2} and 41,200 kw.-hrs. per dkm.^{2} respectively, as compared with 36,800 kw.-hrs. per dkm.^{2} during K2.

Habit of the plants.—As the photoperiod was identical during K1 and M the fact that the M plants were smaller than those of K1 must have been due to one or more of the factors, drought, higher temperatures, or higher light intensity due to less cloud at M. Contrary to expectation drought does not seem to be the cause, because the K2 plants were also smaller than those of K1 and resembled those of M, yet rainfall during their growth was well-distributed and adequate. The smaller size of the M plants was therefore due to higher temperatures and/or higher light intensities.

Werner [13] has shown that leaf-area increases as light intensity or photoperiod decreases. The leaves of M were smaller than those of K1 (Table VIII), and although the light intensities were not measured, the total number of hours of bright sunshine during M were 420 as against less than 300 for K1. In K2 the number of hours of bright sunshine was similar to that of M, and, as already mentioned, the leaves in size resembled those of M. The evidence, though not conclusive, suggests that reduced light intensities were responsible for the larger leaves and possibly the longer stems of the K1 plants.

Flowers were set on the M and K2 plants but not on those of K1. The cause of the failure at K1 was again probably the low light-intensities, for Werner [13] has said that flower and berry production depend on a minimum daily amount of light.

In all experiments the stolons were short and unbranched, but this, according to Salaman [14], is characteristic of the variety. He classified a short-stolon variety as one whose stolons were rarely longer than 8 in. That the stolons of K and M were rarely longer than 6 in. is therefore of doubtful value as evidence that stolons are shorter under short days.

Summary and Conclusions

Potatoes grown at 3,000 and 600 ft. a.s.l. at 5° S. in Tanganyika Territory from Kenya-grown commercial seed of Kerr's Pink can give yields of ware similar to English yields provided that (*a*) the soils are manured on a scale comparable with that of moderate English practice, and (*b*) the plants receive enough water throughout life. Given these conditions the supposed depressing effect of short day-length, ranging between 11·75 and 12·35 hrs., and high temperatures, such as mean monthly maximum air-temperatures between 26¾° and 28¼° C. (80°–83° F.), is of no practical importance.

It should be noted that Kerr's Pink is a main crop variety, which matures during the shortening days of the English autumn, and is perhaps day-neutral in its response to photoperiodism. The above-mentioned conclusions, therefore, hold good only for this variety, though they may apply to other varieties of similar type.

Acknowledgements

I wish to record my thanks to Mr. L. R. Doughty, Director of the Cinchona Research Organization, East Africa, for advice on the layout of the manurial experiments; to Dr. D. W. Duthie, Soil Chemist, Amani, for advice concerning the soils; to Mr. G. B. Wallace, Plant Pathologist, Department of Agriculture, Tanganyika, for the identification of the diseases; to Mr. H. Gillman, Agricultural Officer i/c Sisal Experimental Station, Mlingano, for the loan of a plot of ground there; and especially to Mr. R. E. Moreau, Amani, for the critical reading of this paper.

REFERENCES

1. R. E. Moreau, The Climatic Background to the Problem of Potato Varieties for East Africa. East Afr. Agric. J., 1944, **9**, Nos. 3 and 4.
2. F. Yates, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci., 1937, Tech. Comm. No. 35.
3. H. O. Werner, The Effect of a Controlled Nitrogen Supply with Different Temperatures and Photoperiods upon the Development of the Potato Plant. Nebr. Expt. Stat. 1934, Res. Bull. No. 75.
4. J. C. Wallace, Potatoes. Min. Agric. England, 1941, Bull. No. 94, 2nd ed.
5. Rothamsted Experimental Station, Report for 1936.
6. C. M. Driver and J. G. Hawkes, Photoperiodism in the Potato. Imp. Bur. Plant Breed. and Gen., 1943.
7. B. L. Richards, Pathogenicity of *Corticium vagum* on the Potato as affected by Soil Temperatures. J. Agric. Res., 1921, **21**, 459–82.
8. W. C. Edmundsen, Time of Irrigating Potatoes as affecting Stolon Growth and Tuber Set and Development, U.S.D.A., 1938, Circ. No. 496.
9. W. Stuart, The Potato. 3rd ed. Philadelphia and London, 1928.
10. Information supplied by the U.S.D.A. Office of Foreign Agricultural Relations, 1945.
11. Climate and Man. U.S.D.A. Yrbk. Agric., 1941.
12. Information supplied by the Meteorological Office, Air Ministry, England 1945.
13. H. O. Werner, Relation of Length of Photoperiod and Intensity of Supplemental Light to the Production of Flowers and Berries in the Greenhouse by Several Varieties of Potatoes. J. Agric. Res., 1942, **64**, No. 5.
14. R. N. Salaman, Potato Varieties. Camb. Univ. Press, 1926.

(*Received July 11, 1946*)

SUDANESE CATTLE AS MILK PRODUCERS

B. M. BOYNS

(*Gordon Memorial College, Khartoum, and Department of Agriculture and Forests, Sudan*)

WITH PLATES 1, 2

The Cattle of the Sudan.—The native cattle of the Sudan have been described by Bennett [1] who states that whilst many types exist, three group-types can be distinguished. Two of these, which he designates Northern and Southern, together constitute the great bulk of Sudan cattle. The relatively small cattle of the Nuba Mountains, although few in number, are, he considers, distinctive enough to warrant separate classification.

The northern cattle, with which this paper is concerned, are the cattle of the Mohammedan areas of the Sudan. They have relatively short horns and a well-developed hump. According to Bennett, they were derived from the original humpless African shorthorn (Brachyceros) and the Asiatic (long-horned) Zebu, which had a well-developed cervico-thoracic hump. In addition, Bisschop [2] has described the short-horned Asiatic Zebu which, he states, invaded NE. Africa along with the Arab penetration.

The cattle of the northern Sudan are of a characteristic type, and do not show the high degree of variability that would be expected among the descendants of a fairly recent cross between widely different types such as the African shorthorn and the long-horned Asiatic Zebu. On the other hand, they embody the characteristics of Bisschop's short-horned Asiatic Zebu. From such descriptions as are available, it appears that the important milch breeds of India belong to this group also.

Within the main type some differentiation has gone on in response to the varying conditions under which cattle are kept. In building up the herd here discussed, cows from four different areas were purchased, and there were sufficient differences between them to warrant separate discussion in what follows. The nomadic cattle of the northern Sudan are represented in the herd by the two types designated White Nile and Kenana. Whilst they are similar in general conformation, size, and late maturity, the Kenana type, as a result of the more secluded nature of their habitat, would appear to approach nearer to a separate breed than those from the White Nile. Thus there is much more uniformity in colour in the Kenana cattle, where the apparently recessive blue-grey predominates. The White Nile cattle, on the other hand, show many colours including red, fawn, black, white, and admixtures of these colours.

The types designated Dongola and Shendi cattle were purchased from the riverain areas of the Northern Province. Both these types mature at a much earlier age than the nomadic cattle (3 years as against between 4 and 5). The Dongola cattle from the *sagia*[1] lands of the

[1] *Sagia.* The Persian water-wheel.

extreme North have probably been largely isolated from foreign blood for many generations. Red is the predominant colour, with a few red and whites. They would appear to have been subjected to some degree of selection for work (both cows and bulls are used as motive power for *sagias*) and milk production on the scanty fodder produced by the small-holdings. In the Shendi district, whilst ploughing bulls are very important, irrigation by power-pumps and the consequent more liberal production of fodder is reflected in the very much higher standard of the dairy cows. These cattle, predominantly red of different shades, have probably originated from the nomadic Butana cattle described by Hewison [3] and have been selected for milk by the more enlightened cultivators of the government pump schemes. (Plates 1, 2.)

Previous work on the improvement of Sudan cattle.—As the demand for good-quality beef, either for internal consumption or export, is small and as the northern cattle are in general quite suitable for all the forms of work required of them, the field of improvement is, as Bennett [1] states, limited to that of milk production. In the past little attention has been paid to milk production in the Anglo-Egyptian Sudan, and at first it would appear surprising that in a country with an estimated cattle population of at least 3,000,000 [4] so little information is available as to their dairying potentialities.

Two factors may be said to be responsible for this lack of information: (1) With the exception of a very small fraction (probably of the order of 1 per cent.), the cattle of the country are owned by nomadic pastorals and under such conditions it is virtually impossible to carry out any system of milk recording or effective selection on performance. (2) Owing to the paucity of natural grazing and the relatively high cost of producing forage by irrigation around the more thickly populated areas of the northern Sudan, there has been little incentive to the keeping of sufficient cows to meet the needs of the urban population. What little cows' milk is offered for sale in urban districts is expensive and often much diluted. On the other hand, the goat, with its lower nutritional requirements, is able to produce a limited amount of milk with little addition to a very scanty browsing diet. Consequently the urban dweller, unable to maintain a cow himself, prefers to keep several goats in order to supply his family's needs.

The first attempt to meet the demand for cows' milk created by the small European population was made by the Veterinary Department in 1907, when a dairy was set up in Khartoum, and supplied with forage grown under irrigation. The dairy passed into private ownership in 1932 and still meets the limited requirements of the normal European population. Little further progress was made with improvement of dairy cattle until the war caused a sudden increase in the demand for cows' milk.

Such attempts at improvement as were made before the war were all based on the importation of European bulls. According to Bevan [5], the brothers C. and G. Nevile imported a Devon bull about 1918 or 1919 and used it on the native cattle of their two pump schemes in the Northern Province. When Bevan visited one of these pump schemes in 1921 he found that although the bull had not survived, it had left

numerous progeny. The first cross were humpless and very superior milkers to their native parents. The cows were much more docile, but the bulls, which were used for work despite the lack of hump, were inclined to be more pugnacious than their native parents. When the herd was dispersed in 1926, several heifers from this stock were bought by Bevan for Government pump schemes, and stud bulls containing this Devon blood are still very popular among the native cultivators. The hump appeared to return in about the fourth (backcross) generation.

Bennett [1] records the attempts of the Sudan Veterinary Service to improve the cattle of the Khartoum dairy by importing Friesian stock from Europe. It was found that even when maintained under the best available conditions from the moment of importation, they rarely survived more than a few weeks. Half-bred or quarter-bred bulls, descended from the few which survived long enough to beget progeny, have been found to thrive under the artificial conditions of Khartoum, but when sent to outstations they invariably succumbed without leaving further progeny. The Khartoum dairy herd is, at present, largely composed of these cross-bred Friesian cattle. The failure of European stock to withstand the conditions of this country are ascribed by Bennett to an 'incurable blood infection which all Sudan cattle harbour without damage to themselves'. French [6], on the other hand, discussing the same difficulty with European cattle imported into British E. Africa, concluded that their failure resulted from inherent physiological unsuitability to a tropical climate.

The foundation of the Shambat herd.—The development of military operations on the Sudan borders in the autumn of 1940, and the consequent influx of service personnel into Khartoum, created a demand for liquid milk far beyond the available supply. It was, therefore, at the request of the military authorities that the Principal of the School of Agriculture on behalf of the Director of Agriculture undertook to set up a dairy herd and produce a supply of fresh milk for the use of the military hospitals. This Military Dairy's herd was the foundation of the present Shambat herd, and was taken over by the School of Agriculture in January 1945, when the Services' demand for extra milk came to an end.

The herd was got together hastily in response to an urgent demand for milk in the autumn of 1940, and newly calved or down-calving cows were purchased where they could most conveniently be obtained. Consequently the herd was founded on both nomadic and northern riverain cattle, and as a result some comparison is available between these different types.

To meet immediate requirements 61 head of cattle were purchased in October 1940, of which 8 (7 in milk) were selected from the Shendi irrigated areas, 33 (26 in milk) were bought on inspection from the White Nile nomadic pastorals, and 20 (12 in milk) from the nomad herds of the Kenana district of the Fung. These, when added to the two cows of the White Nile type already at Shambat, produced 46 cows in milk with additions calving every day. A further 51 cows (29 in various stages of lactation), which had been bought at random from the basin areas and

sagia cultivations in Dongola, arrived during November. During the subsequent three months, as a result of the continued and increased demand for milk, the size of the herd had to be doubled, mainly by the purchase of unselected nomadic cattle.

TABLE 1. *Summary of Data showing the Number and Source of the Foundation Cows purchased*

Source of cattle	*Riverain and Basin areas of Dongola*	*Pump Schemes of Shendi District*	*White Nile nomads*	*Kenana (Fung) nomads*	*Total*
Cows purchased in milk	29	18	45	17	109
Cows purchased in calf, calved and milked	15	2	50	14	81
Cows proved to be barren and discarded	7	..	20	1	28
Deaths and casualties	..	..	..	5	5
	51	20	115	37	223

Of the five casualties shown against the Kenana type of cattle, 1 was the result of a broken leg occurring in transit and the other 4 were victims of a tick fever which developed when they were brought north.

Results

Season 1940–1.—A total of 190 cattle were milked and recorded in the period Nov. 1940–Dec. 1941, yielding 346,552 lb. of milk in 38,406 cow-days, or an average of 9 lb. per cow per day for a mean lactation of 202 days. These figures include every cow in milk and record total yields of from 28¾ lb. to 5,157 lb. for periods varying from 14 days (6 cows) to 434 days.

Lactation records are available for 81 cows that were recorded from date of calving (Table 2).

TABLE 2. *Summary of Complete Lactations 1940–1*

Type of cattle	*Total no. of complete lact.*	*Mean yield per lact. (lb.)*	*Mean length of lact. (days)*	*Mean yield per cow per day (lb.)*	*Range in lactation yield (lb.)*	*Range in length of lactation (days)*
Dongola . .	15	1,666·5	168	9·9	3,969– 29	322– 21
Shendi . .	2	2,656·5	227·5	11·7	4,211–1,102	294–161
White Nile .	50	1,876·0	198	9·5	4,791– 29	378– 14
Kenana, Fung .	14	2,442·5	251	9·7	5,157– 82	392– 26
Total . .	81	1,954·0	202	9·7	5,157– 29	392– 14

Whilst the Dongola cattle do not show up very well in comparison with the nomadic White Nile and Kenana cattle, it should be noted that this year's results were not a fair comparison, as the Dongola cattle had arrived in very poor condition, following a crop failure due to a low river in the previous season; furthermore, the proportion of old cows was abnormally high, 5 of the 15 being estimated at over 10 years of age.

The 50 White Nile cattle can be considered to give a very fair indication of the yields to be expected from an average sample of nomadic cattle; 45 of these cattle were purchased without selection in Jan. 1941 when the demand for milk was most pressing. Indeed, as the nomadic grazier will never part with his best animals, the mean yield of 180 gals. is probably a low estimate of the average to be expected from these animals under adequate conditions of nutrition and normal twice-a-day milking.

The Kenana cattle had been subject to a degree of selection when purchased, and only 3 of the 14 cows shown above had lactations of

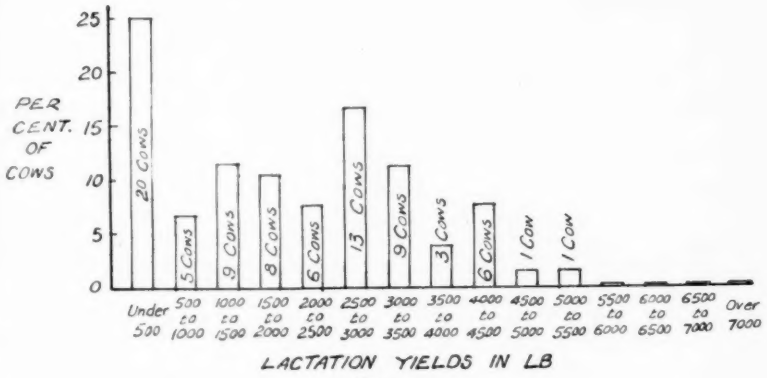


FIG. 1

less than 145 gals. or milked for less than 210 days. One of these died suddenly (cause unknown) 26 days after calving, and the other two had their lactations spoiled by mastitis.

The frequency distribution of the 1940–1 lactations is shown in Fig. 1.

TABLE 3. *Summary of Lactations 1942*

Source of cattle	*Total no. of complete lact.*	*Mean yield per lact. (lb.)*	*Mean length of lact. (days)*	*Mean yield per cow per day (lb.)*	*Range in lactation yield (lb.)*	*Range in length of lactation (days)*
Dongola . .	21	2,381	192	12·4	4,267–177	343–35
Shendi . . .	14*	3,725	255	14·6	6,393–331	427–42
White Nile . .	32	3,140	274	11·4	6,235–667	448–70
Kenana, Fung .	19	3,089	266	11·6	7,072–277	490–77
Total . .	86*	3,039	249	12·2		

* Including one heifer lactation.

Season 1942.—As a basis for selection, 200 gals. in 1940–1 was taken as a minimum yield, allowances being made for cattle whose lactation was not a complete one. This standard, however, could not be applied

to the Dongola-type cows, as culling on old age and poor condition limited the number available for selection to 21, of which only 14 had attained the 200-gal. mark in the previous season. Again, as total numbers were small, 15 of the 20 Shendi type were retained, to which was added one heifer. Of the 41 White-Nile type that had reached 200 gals. 30 completed a second lactation in 1942, 10 of the remainder not being in calf again (4 eventually calved in 1943), and one dying as a result of vaccination. Two animals that had not reached the 1941 limit were given another trial, making a total of 32.

The 19 Kenana cattle milked in 1942 were made up of 16 that had given over 200 gals. in 1941, 2 that had not attained this level, and an in-calf cow purchased along with 17 others in milk in the late autumn of 1941.

The increase in the mean yield of the herd by over 100 gals. is the more noteworthy when the fact is taken into consideration that of the 86 cows recorded, 12 had no dry period, 5 one week only, 5 two weeks, 6 three weeks, 3 four weeks, and 6 five weeks only before calving. The distribution of the 86 lactations is shown in Fig. 2. The best two lactations in 1942 were 7,072 lb. in 490 days and 6,393 lb. in 329 days, and the mean yield per cow per day was 12·2 lb., against 9·7 lb. in the previous year.

Season 1943.—The strain of milking for two lactations without any rest period was reflected in the 1943 results, where no fewer than 21 cows could not be stocked in time to give a lactation in 1943. The demand for milk did not allow for any drastic culling of cattle at the beginning of the season; in fact the 8 cows that left the herd (senility accounting for the majority) were replaced by 12 new Kenana cow lactations, plus 6 of the heifers that had arrived with their dams in 1940 (Table 4).

TABLE 4. *Summary of Lactations for 1943*

Source of cattle	*Total no. of cattle*	*Mean yield per lact. (lb.)*	*Mean length of lact. (days)*	*Mean yield per cow per day (lb.)*	*Range in lactation yield (lb.)*	*Range in length of lactation (days)*
Cows						
Dongola	16	3,191	245	13·0	5,421–1,072	308–112
Shendi	6	5,393	289	18·7	6,887–3,488	329–231
White Nile	24	2,990	257	11·6	5,987– 568	413–119
Kenana	25	3,181	267	11·9	5,577– 762	427– 84
Total cows	71	3,306	261	12·7		
Heifers						
Dongola	3	1,932	180	10·8	3,058–1,305	294–112
Shendi	3	2,195	198	11·1	4,272– 464	315– 84
Total	77	3,209	255	12·6		

The distribution of the 77 lactations is given in Fig. 3. Of the 6 heifers only 2 showed any promise of being as good as their dams and these only were retained for further trial.

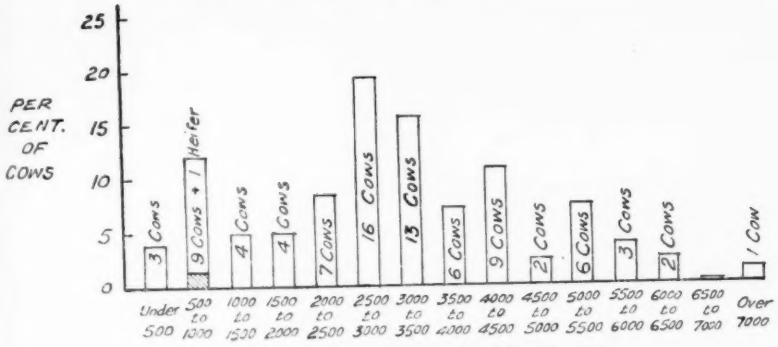


FIG. 2

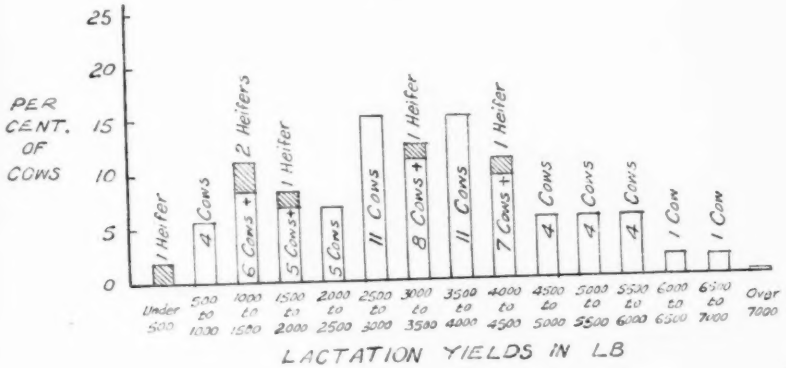


FIG. 3

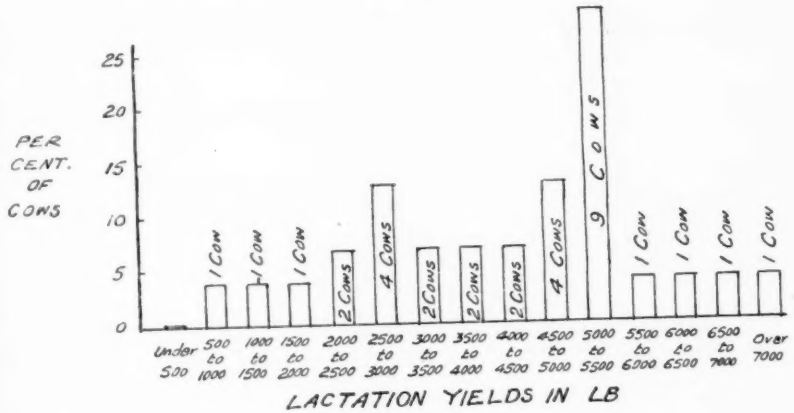


FIG. 4

Season 1944.—While the demand for milk was great two dairies were maintained, one at Shambat and one near the Military Hospital at Wadi Seidna. The Services' requirements were much reduced in May 1944, and the herd was cut down accordingly and the Wadi Seidna dairy closed. Consequently, whilst the cows calving in the early part of the year had not been subject to severe culling, those calving from April onwards were culled at a level of 500 gals. This is reflected in the 32 lactations for foundation cows recorded in Table 5, the distributions of which are shown in Fig. 4.

TABLE 5. *Summary of Lactations 1944*

Source of cattle	*Total no. of cattle*	*Mean yield per lact. (lb.)*	*Mean length of lact. (days)*	*Mean yield per cow per day (lb.)*	*Range in lactation yields (lb.)*	*Range in length of lactation (days)*
Cows						
Dongola . .	6	3,228	245	13·2	5,372–1,384	365–126
Shendi . .	7	4,875	283	17·2	6,574–2,627	322–217
White Nile .	11	4,366	307	14·2	5,967–2,229	400–189
Kenana, Fung .	8	4,990	298	16·7	10,272– 881	630–119
Total . .	32	4,420	288	15·4		
Heifers						
Shendi . .	2	3,158	280	11·3		
White Nile .	1	2,347	280	8·4		
Home-bred Riverain Dams	3	3,383	253	13·4	5,545– 452	395– 64
Total Heifers .	6	3,135	267	11·7	5,545– 452	420– 64

The outstanding lactation was that of the Kenana cow 'Gazalla' 5/22, which, after calving on June 5, 1944, yielded 10,272 lb. in 339 days, attaining a maximum daily yield of 52 lb. with a minimum butter-fat content of 4·35 per cent. Another Kenana cow, which had produced 500 gals. in 1941 and 1942, calved in August 1943 and milked all through 1944 to yield 9,325 lb. in 630 days.

Discussion

The first essential in building up a dairy herd from native cattle is drastic culling on performance and the establishment of an *élite* stock. There occurred early in 1944 an opportunity to cut the Shambat herd down to about half, and cows with poor records were disposed of. Twenty-five of the 32 cows milked in 1944 were also milked in 1942. The distribution of their lactations in 1942 is given in Fig. 5 and their lactation records summarized in Table 6. It will be seen that the 25 *élite* cows included nearly all the best milkers and very few of the poorer milkers in the 1942 herd. Their average yield was 3,874 lb. in a mean lactation of 299 days in 1942, as compared with the average yield of 3,039 lb. in 249 days for the whole herd.

Culling, however, is only a preliminary to milk production, and any real improvement must be based on better management. Good manage-

ment is the sum of a great number of different factors, of the separate effects of which no analysis can be made. Nevertheless, an indication of the overall effect of improvement in management between 1942 and 1944 is obtainable from a comparison of the lactation records of the 25 *élite* cows milked in both years (Figs. 5, 6, and Table 6).

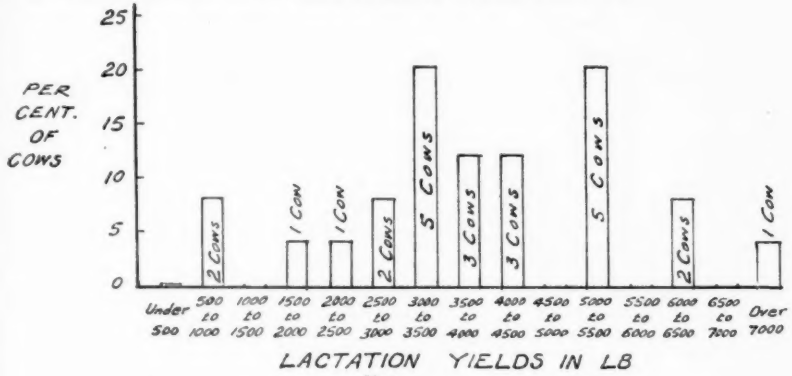


FIG. 5

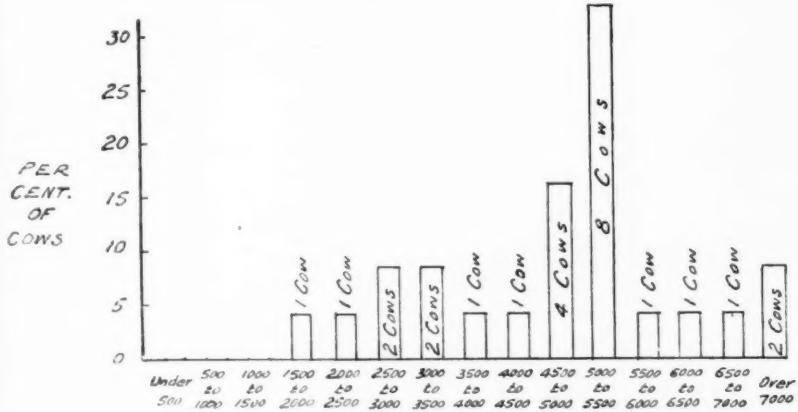


FIG. 6

TABLE 6. *Summary of the Lactations of the 25 Cows which milked in both 1942 and 1944*

Year	*Mean yield per lact.* (*lb.*)	*Mean length of lact.* (*days*)	*Mean yield per cow per day* (*lb.*)	*Range in lactation yields* (*lb.*)	*Range in length of lactation* (*days*)
1942	3,874	299	13·0	7,072– 832	490– 77
1944	4,929	310	15·9	10,272–1,639	630–189

It will be seen that performance was considerably better in the later year, there being an increase in the average lactation of 100 gals., and the mean yield per cow per day in milk rose by 3 lb., or over 20 per cent.

Two of the most important factors in efficient management are expert stockmen and an adequate plane of nutrition. Nomadic pastoral conditions produce neither good stockmen nor adequate feed, and even on the areas irrigated by pumps, where slightly better conditions of feeding are found, the stockmen are not competent to make the best use of their advantages. The complete failure to recognize the value of these cattle as milk producers in the past was probably a consequence of lack of appreciation of the limitations of the native stockmen. These limitations became apparent at the beginning of the present study, when the necessity for milk-recording arose. From the outset it was deemed essential that complete individual daily records of the milk yields should be kept. Not only would this make possible the culling of unprofitable milkers and thus ensure that some selective breeding policy could be adopted, but it would also produce some data on the milking capacities of the average Sudan cow under improved conditions of management and feeding.

The native practice of allowing the calf access to the cow, in order to encourage the latter to let down her milk, is universal in the Sudan, as it would appear to be elsewhere in the tropics where Zebu-type cattle are kept [7]. Opinion of both European and Native in this country was that to produce milk without the presence of the calf at milking-time was an impossibility [3]. It is worth noting, however, that in India the Zebu cattle of the Military Dairies have been induced to milk without their calves present, and that Wood [7] suggests that the appearance of the word 'tulchan' in any standard dictionary is evidence that this practice has not so long been discontinued in Scotland.

To the pastoral Arab with a large herd of cows in milk, and a very limited demand for the milk, such a practice has many advantages. Cows returning to the *fariq*,[1] where their calves have been confined, naturally stand and allow their calves to suckle. This enables the herdsman to secure the cow and extract that portion of the milk which the cow has already 'let down'. The necessity for 'milking out' the udder is dispensed with as the hungry calf acts as an efficient stripper. The Arab, who converts all surplus milk into clarified butter, loses a large proportion of the butter-fat by this method, but the extra share that the calf gets in the strippings is probably of vital importance to its survival under the pastoral conditions of the country. Such a practice makes milk-recording impossible. Moreover, in a commercial dairy it is unhygienic, and it severely limits the amount of milk available for sale since it is necessary to maintain numerous unwanted calves.

The 'letting down' of milk is brought about by a nervous reflex, the result of a combination of stimuli [8, 9]. An important natural stimulus is the suckling of the teats by the calf, and the manipulation of the teats by the milker becomes associated with it. Western dairy practice

[1] *Fariq*. Temporary encampment of nomadic Arabs.

has shown that the cow can be 'conditioned' to associate other stimuli with this reflex, provided no adverse conditions of excitement, fright, or pain intervene to distract her [9]. The nomadic cattle of the Sudan in their own environment tend to be rather wild and nervous, and are often encouraged in this habit by the herdsmen so that they are difficult of approach by strangers. It was obvious, therefore, that the first step in eliminating the presence of the calf at milking-time was to accustom the cows to handling and to avoid anything of a disturbing nature.

The Arab herdsman, imbued with ideas handed down from generation to generation in the *fariq*, was soon found to be a most unsuitable assistant when making this change, and as far as possible men unused to cattle were employed. Such men, more sophisticated by their contact with civilization, adapted themselves much more readily to western ideas of cattle management. Although they have not the 'eye' for cattle that the Arab possesses, they are superior to him in every other respect, including milking ability. (The head cattleman at Shambat had been an employee of the River Steamers Department before being engaged as a herdsman in 1940.)

On arrival at the farm the newly purchased cattle were allowed 15 days in which to settle down, and every effort was made to accustom them to concentrates. Those in milk were milked twice daily with the calves at foot, and the opportunity was taken of selecting milkmen who would be amenable to instruction in dairy husbandry. Recording of milk yields started on Nov. 15, 1940. The calves were allowed in front of the cows but not allowed to suckle, so that the whole of the milk yield was recorded. After a further 15 days the calves of 37 nomadic cattle that had arrived in milk at the end of October were removed completely from the herd and the cows milked in the normal way. Table 7 shows the mean yield of these cows for the 15-day periods preceding and following the day the calves were removed.

TABLE 7

No. of cows	*Mean yield per cow for 15 days prior to removal of calf (lb.)*	*Mean yield per cow for 15 days after removal of calf (lb.)*	*No. of cows showing increased yield*	*No. of cows showing decreased yield*
37	146·3	152·8	25	12

It will be seen from the above figures that less than a third of the cows showed a drop in yield after taking the calves away. Of the 12 cows which lost milk only 2 were giving a gallon or more per day at the beginning of the experiment, and one of these picked up again later and went on to give 334 gals. in the 294 days it was recorded. Twenty-eight of the 37 cows had bull calves (of unknown sire) at foot when purchased. All bull calves were disposed of when it was found that their dams would milk without them. As they consumed about 10 lb. of milk per head per day, the disposal of unwanted calves alone effected a daily saving of 280 lb. of milk.

The experiment having proved successful, the calves were removed from all other cows in the herd and the cows milked in the normal manner. Since then the native practice of having the calf present at milking-time has never been reverted to, the calves being taken away from the dam at birth and, if to be kept, reared on the bucket. A few potential milkers were probably lost by adopting this technique, but nothing approaching the proportion lost in the Shendi herd, from which Hewison [3] drew the conclusion that the removal of calves from native foundation cows was not a feasible practice. It may be suggested that the discrepancy between Shambat experience and results at Shendi and elsewhere is due to failure to take into consideration the psychology of the average Sudan herdsman. In any case it is evident that if any improvement is to be attained the practice of milking with the calf at foot must be eliminated, by drastic culling if it is inherent in the cattle or by the selection and training of better stockmen if it is a matter of traditional belief.

The nutrition of the nomadic cattle in the northern Sudan is controlled by the length and amount of the annual rains. During the second half of the rains pasture is generally abundant, and probably more than 80 per cent. of the total lactation yield is obtained on this grass, daily yields of 1½ gals. and more being quite common. The end of the rains and the consequent drying off and dying of the natural grazings, accompanied in many cases by a scarcity of drinking-water, results in a rapid falling off in milk yield. The average lactation under pastoral conditions is seldom longer than 5 months. During the late summer, before the break of the rains, the majority of the cattle, instead of being 'steamed up' for the forthcoming lactations, are more often fighting a race against death by wasting away. The idea of conservation of excess fodder during periods of plenty has not yet reached the nomad, who attempts to make up for his losses during the dry season by promoting an increase in numbers during the rains.

Little better conditions exist on the *sagia* cultivations in Dongola district where some storage of fodder is practised. Here the available forage is limited by the capacity of the small-holding and the height of the Nile flood, whilst the number of animals per holding is primarily determined by the motive power required to turn the water-wheel. The milch cattle of the pump schemes, on the other hand, are better off, as the forage required for the working oxen on the *sagia* can be given to the milking cows. In general it may be said that under most native conditions the initial limiting factor in production of milk is inadequate nutrition, the problem being not so much one of ill-balanced feeding as one of starvation during the greater part of the year.

The sudden decision to set up the Military Dairy in 1940 had allowed no time for the provision of a fodder farm. Thus for most of the first year the greater part of food for the cattle had, of necessity, to be bought in, and very little choice was available. The only bulky fodder that could be obtained in sufficient quantity and at a reasonable cost was poor-quality dura *gassab* (the straw of *Sorghum vulgare* left after the grain has been harvested). This was imported from the rain cultivation areas. It

was hoped that this fed *ad lib.* would supply the bulk and part of the maintenance ration, and that a mixture of native-pressed simsim (*Sesamum indicum L.*) cake and dura grain would supply the remainder required for maintenance, as well as provide for production of milk. Whilst the latter two provided an excellent concentrate ration for milk production, it was believed that higher yields could be obtained if the dura *gassab* were supplemented with a more succulent and better-quality fodder. It was possible to verify this belief in that part of the herd situated at Wadi Seidna. There some 20 acres of *negeel* grass (*Cynodon dactylon*) had been laid down in the previous spring. This provided enough grazing for the first two months until some arrangements could be made to produce forage by irrigation.

The provision of a part of the ration in the form of a succulent is thought to have played a prominent part in the increased yields obtained from the individual cows in succeeding lactations, although, owing to the multiplicity of factors involved, it has not been possible to assess the particular increase due to any one of the improved conditions of management. Dura fodder, hayed in the flowering stage, still supplies the major part of the bulk in the ration, supplemented with river-grass hay when this can be obtained economically. The succulent part of the ration has been provided, in the main, by sowing in addition to dura such crops as *lubia* (*Dolichos lablab*), maize (*Zea mays*), Sudan grass (*Sorghum Sudanense*), sunflowers (*Helianthus annuus*), and a small area of Berseem (*Medicago sativa*).

The composition of the production ration has always been determined by the local concentrates available and not required for human consumption. Thus in 1940 and early 1941 simsim cake (1 part) and dura grain (2 parts) were fed. The increased cost of simsim cake, and the fact that the native-pressed cake deteriorates rapidly on storage, led to its replacement by locally produced, machine-pressed cotton-cake, and the mixture was altered to equal parts of cotton-cake and dura grain. No ill effects on milk production were noticed as a result of this change. The shortage of dura grain for human consumption in 1944 necessitated a gradual reduction of the proportion of this carbohydrate and its eventual replacement by Sudan-grown maize, and at the present time the concentrate ration consists of 2 parts cotton-cake and 1 part maize meal plus a locally produced mineral supplement, again without any ill effects on the yields. The carbohydrate being the most expensive part of the ration in this country, use has been made whenever possible of any cheaper sources, e.g. surplus sweet potatoes, waste sugar, &c., for substituting part of the carbohydrate in the ration.

In the absence of data for the feeding-values of the foodstuffs of the Sudan, calculations of rations have necessarily been approximate only, but it should be noted that allowance has been made for the very much higher butter-fat content of average Sudan milk. The butter-fat content of the milk of this herd is over 5·5 per cent. and this has necessitated the feeding of the production ration at the rate of 5 lb. per gal. of milk.

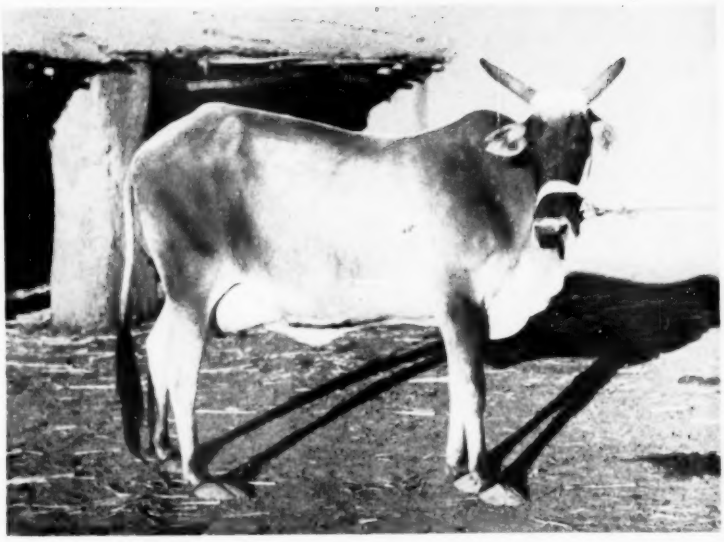
From the results obtained it would appear that provided a small amount of succulent forage is available, there is no reason why a herd-

average of at least 400 gals. per annum should not be possible from the cattle of the northern Sudan under conditions of feeding and management well within the reach of any native cultivator. That certain of these indigenous cattle are capable of very much higher lactation yields when specifically fed for milk is shown by the cow Gazalla 5/22. This cow was chosen for experiment to see what improvement could be brought about by substituting a large proportion of the roughage by green legume fodder (*Medicago sativa*), and by paying particular attention to such herd-management factors as 'steaming up' and expert milking. Gazalla 5/22 is a Kenana-type cow. She was purchased in Nov. 1940 and her lactation records thereafter were 426 gals. in 1941, 333 in 1942, and 540 in 1943. In March 1944 it was decided to steam her up for her 1944 lactation. She was fed the same concentrate mixture as the remainder of the herd, but the quantity was gradually increased until she was getting 10 lb. per day when she calved down on June 5, 1944. The best milker on the farm was put in charge of her, and she was milked three times a day for the first 20 weeks of her lactation. The peak daily yield was 52 lb. with a mean butter-fat content over the 24 hrs. of 4·35 per cent. She was dried off after 339 days, having given 10,272 lb., or an average of 3 gals. per day over the whole period.

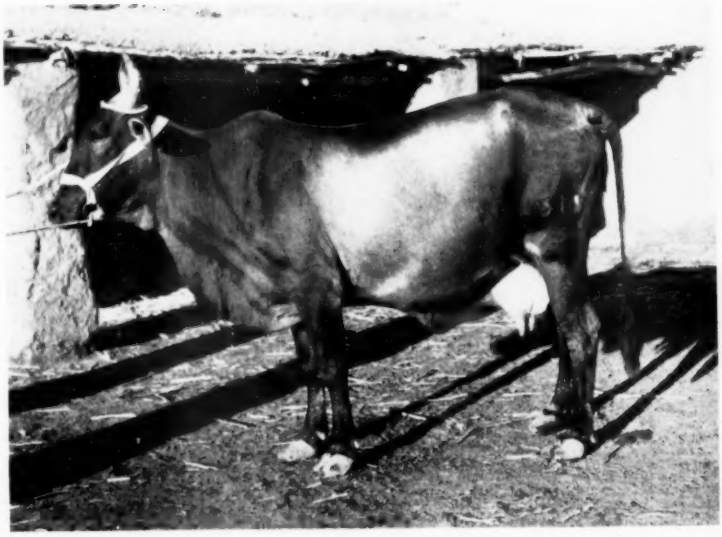
In conclusion it should be emphasized that almost all the animals for which records are available are foundation stock, bred and reared in native herds. Even so their capabilities compare favourably with those of Zebus in other parts of the world. They are not up to the standard of the premier Indian breed, the Sahiwal, whose average lactation yield, after a quarter of a century or more of management and selection, is over 7,000 lb. [10]. Nevertheless, the Shambat yields for 1944 compare very favourably with those given by Ware [10] for the pedigree herds of Tharparkar, Hariana, and Sindi cattle, and the individual yield of 10,272 lb. given by the Kenana cow at Shambat in 1944 exceeds the maximum of any of these last three breeds. Compared with Zebu cattle of E. Africa, where yields of 300 gals. per lactation are considered high [11, 12], the Sudan cattle are outstanding. Thus of 208 cows milked during the period 1940–4, 77 (37 per cent.) gave over 300 gals., 42 (20 per cent.) had lactations greater than 400 gals., and 25 (12 per cent.) greater than 500 gals.

It would appear from the results so far obtained that the Sudan possesses in its cattle an excellent basic material capable of rapid response to selection. They have all that is necessary for the establishment of a productive local dairy industry without the introduction of European blood. Moreover, with their hardiness and suitability to a tropical climate, combined with a good standard of milking capacity, they will compete very favourably with the best Indian breeds for use in improving milk production in other tropical countries.

Acknowledgements.—The author wishes to express his grateful appreciation of the assistance received from Mr. G. H. Bacon of the Department of Agriculture and Forests (and formerly Principal of the School of Agriculture), who instigated this investigation and gave both

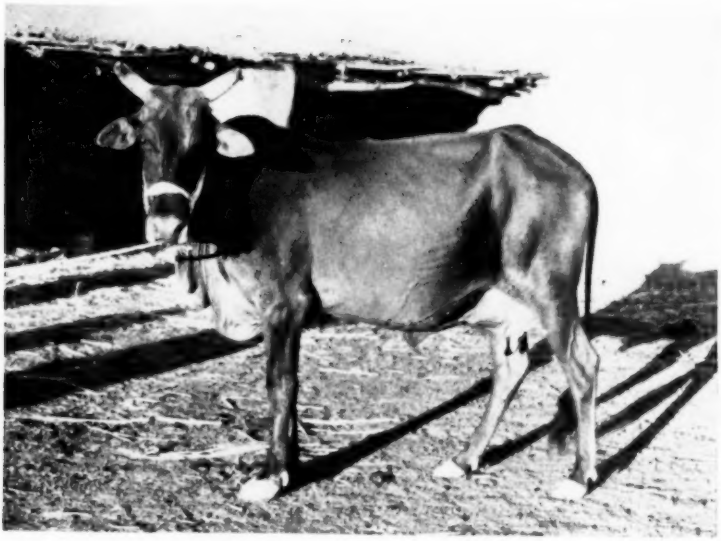


White Nile type. Foundation cow



Kenana, Fung type. Foundation cow

SUDANESE MILCH CATTLE



Dongola type. Foundation cow

Shendi type. Foundation cow

SUDANESE MILCH CATTLE

advice and encouragement throughout. Also to Mr. J. B. Hutchinson, Chief Geneticist of the Empire Cotton Growing Corporation, for the generous help he gave in the preparation of this paper.

REFERENCES

1. S. J. C. Bennett, Dept. Econ. & Trade, Sudan Govt., 1938, Bull. No. 1.
2. J. H. R. Bisschop, S. Afr. J. Sci., 1937, **33,** 852.
3. J. W. Hewison, East Afr. Agric. J. 1945, **11,** 104.
4. C. P. Fisher, Rept. Soil Conserv. Comm., 1944, Appendix XV, Sudan Govt.
5. T. D. Bevan, Personal communication, 1945.
6. M. H. French, East Afr. Agric. J., 1941, **6,** 189.
7. R. C. Wood, Cattle in the Tropics, 1934. Govt. Printer, Trinidad.
8. J. Hammond, Vet. Rec. 1936, **16,** 519; abstract in East Afr. Agric. J. 1937–8, **3,** 158.
9. D. Espe, Secretion of Milk, 1941, Iowa State Coll. Press.
10. F. Ware, Empire J. Expt. Agric. 1941, **9,** 1.
11. R. H. Cameron, East Afr. Agric. J., 1945, **11,** 20.
12. H. C. W. Guy, ibid., 1937, **2,** 319.

(*Received July 25, 1946*)

THE CONTROL OF ECTOPARASITIC INFESTATIONS OF FARM STOCK WITH 'GAMMEXANE', WITH SPECIAL REFERENCE TO THE ARSENIC-RESISTANT BLUE TICK

J. A. THORBURN

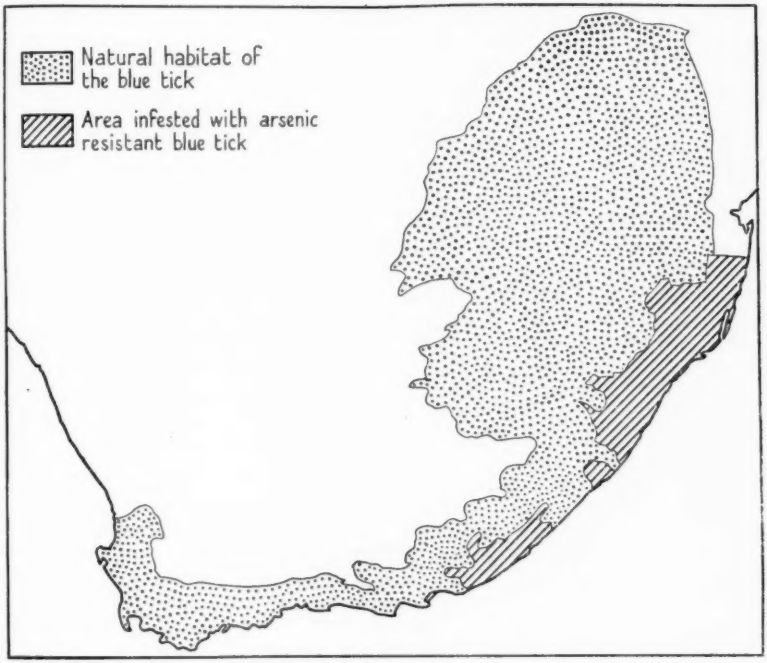
Introduction.—'Gammexane' is the name given to the gamma-isomer of hexachlorocyclohexane, $C_6H_6Cl_6$, by Imperial Chemical Industries Ltd. It is one of four isomers that differ in their atomic arrangement, solubility, and melting-point. These isomers are distinguished by the prefixes alpha, beta, gamma, and delta, and in the trade products ('666') are present in the approximate proportions of 70, 5, 10, and 15 per cent. respectively. The gamma-isomer is responsible for almost all of the insecticidal activity of this product. It is stable to heat and acidity, does not oxidize on exposure to air, but is not so stable to the action of strong alkalis. As an insecticide it is of the highest veterinary significance, as it is not only lethal to a wide range of insect species, but is effective at very low concentrations. It has been found to be a true insecticide, in that it kills but does not repel the parasitic life against which it is active. It is a slow-acting poison, affecting the nervous system, and being stable but slightly volatile retains its efficiency for a long time. In these respects it resembles DDT.

The field investigations recorded in this paper have all been carried out in the East London district, Cape Province, from August 1945 to May 1946; and of special significance has been the work done and the results obtained by the use of dip-washes containing 'Gammexane' against severe infestations of cattle by the arsenic-resistant blue tick. This district was selected because it not only harbours a wide range of ectoparasitic infestations of stock, but also was the district chiefly concerned in the original investigations conducted by the Division of Veterinary Services in 1940, which established the occurrence of an arsenic-resistant or arsenic-tolerant strain of the common blue tick *Boophilus decoloratus* (Koch). Since then every effort has been made by scientists and chemists of Government and commercial houses to find some effective economical dip-wash that would be available in sufficient quantity to control the very severe and widespread infestation of this tick.

1. *The Arsenic-resistant Blue Tick: Infestations of Cattle*

History.—The light-shaded zone on the map is the natural habitat of the blue tick *Boophilus decoloratus* (Koch). The dark-shaded zone shows the area known to be infested with the arsenic-resistant strain of this blue tick. Although the latter area may appear to be small, it nevertheless affects some of the major stock-raising belts in the Union. Since 1940, when it was proved that this resistant strain infested cattle in the East London, Komgha, and Kingwilliamstown districts, investigation has shown that the extent of this infestation has progressively developed, and to-day more than 46 districts are known to be infested with it. In

the author's opinion there is no factor that will inhibit its spread, and it is only a question of time before it will be found throughout the Union, infesting all belts of natural habitat of the blue tick. Thus, this resistant tick has become a real menace, and the question of its effective control one of vital importance to agricultural interests and economy.



It was therefore decided to conduct controlled dipping experiments in the East London district, on farms with cattle known to be badly infested with this tick, to ascertain whether the preparations used would prove effective against it and, if effective, to determine the concentration and interval of dipping required to obtain and maintain this effective control.

Spraying test.—As a preliminary safety measure, before undertaking any full-scale dipping experiments, it was considered expedient to carry out spraying tests on cattle infested with this tick with washes containing 'Gammexane' at a wide range of concentrations. Two emulsion-type dips and one suspension-type dip were used to make up the spray washes to be tested. The observations recorded proved very informative, and indicated that washes containing 'Gammexane' at concentrations ranging from 0·025 to as low as 0·0064 per cent. markedly reduced this tick infestation, affected all stages of this one-host tick, showed a temporary residual protection against larval reinfestation, and proved safe to use.

Dipping tests.—Following the above preliminary tests, 'Gammexane' dips consisting of one suspension-type preparation and three emulsion-type preparations were used in field experimental dipping trials.

The procedure followed in all these trials was to select a representative tank unit, having the dipping tank and its races thoroughly cleaned out and then filled to a measured capacity, which was recorded on a measuring stick specially provided for the purpose. This enabled an accurate record to be kept of the dip-tank levels from one dipping to the next, since at every dipping the level of the settled surface of the dip-wash was taken before and after each dipping. The dip-wash strength, therefore, could be adjusted as the need arose. This method of maintaining dip-wash concentration had to be adopted because, as yet, there is no field method for testing the 'Gammexane'-content, though a laboratory test can be carried out.

At each dipping, before any cattle were dipped, the dip-wash was thoroughly mixed to ensure an even strength of the wash. A sample of the wash was taken at the end of each dipping for test and observation. The cattle dipped in any unit were divided into: (1) a large group, including the milking cows and breeding stock, dipped every 7 days (the 7-day group); (2) a group including oxen and dry cattle dipped every 14 days (the 14-day group). Where considered necessary these two groups were specially marked to facilitate the identification of any group. This was usually done by clipping short the tails of the one group; (3) a small control group. At spaced intervals a few head of cattle were left undipped for a short period to observe the development of the blue-tick infestation. Fully engorged adult females were taken off from time to time and, to test their resistance, subjected to *in vitro* tests with arsenical dip-washes at the 0·16 per cent. arsenic-trioxide strength. In addition inspections were held on adjoining farms of cattle dipped regularly in arsenical dip-washes of the prescribed strength. Throughout the period of test this blue tick continued to show arsenic-resistance. When inclement weather prevented the routine dipping of any unit the cattle groups of that unit were dipped on the first suitable day thereafter, but came back to their fixed day at the following dipping.

A close inspection was made of the cattle of each dipping-interval-group, of all tank units, on every dipping day. This was done both before dipping and when dipping was in progress as the cattle were draining off. The groups were examined collectively and then individually in a control race for the presence of this blue tick in any one of its three stages. The individuals examined in this way always included the cattle found to be most prone to this infestation, such as milking cows, bulls, lame and poor-conditioned cattle, and any other cattle that the owner reported to be susceptible to this tick-life. Thus this examination was a very fair test for ascertaining the tick-life and its stages present on the cattle at the time of these checks.

Throughout these experiments all the cattle were closely observed for any signs of adverse effect. A record was kept of weather and veld conditions. Attention was paid to the influences of condition of the cattle

and climatic factors on the incidence and degree of tick-infestation. In general, for the 10 months reviewed, the average rainfall over the district was 18 in., grazing conditions were adequate to maintain the cattle in fair condition, and climatic factors were suitable for tick-life.

Tank units.—Experimental dipping trials were carried out with 11 tank units, carrying 24 herds of cattle, totalling 2,400 head of cattle. For the period reviewed over 36,000 head of cattle were dipped. These units were known to have been infested with this resistant blue tick since 1940. The tests were started after a long period of drought. The cattle in these units were then in poor condition and anaemic, due to the effects of gross tick-infestation and poor grazing. The skins of the animals had become hardened and often cracked in the region of the escutcheon, brisket, and neck, from rubbing set up by the continuous irritation of the tick over these sites. The ticks were generally distributed over the whole body, with gross infestation of the usual predilection sites.

Dip-washes employed.—The suspension-type dip was used in dip-washes at 'Gammexane' concentrations ranging from 0·0064 to as low as 0·0021 per cent. The three emulsion-type dips were used in dip-washes at 'Gammexane' concentrations of 0·0051 down to 0·0013 per cent.

In two tank units a composite dip-wash was used. One unit contained an arsenical dip at the prescribed 7-day strength of 0·16 per cent. arsenic trioxide plus the suspension-type 'Gammexane' dip at a concentration of 0·0025 per cent., and the second unit contained arsenic at the same 7-day strength plus one of the emulsion-type 'Gammexane' dips at a concentration of 0·0013 per cent. for the first two months of the test, and then at a concentration of 0·0025 per cent. thereafter.

Object of the tests.—The main object of these trials was to ascertain if these dip-washes would effectively control this tick-infestation when the cattle were regularly dipped; effective control meant the killing off of all infesting larvae of this one-host tick so that none of them could develop into their nymphal and adult stages.

The first dipping trial conducted, with a suspension-type dip-wash at a 0·0064 per cent. 'Gammexane' concentration, was very promising and showed that it had effected a complete control by the fourth weekly dipping, which was maintained thereafter.

The next important object was to determine the interval of dipping and the minimum effective concentration of 'Gammexane'.

The object in testing a composite dip-wash containing 'Gammexane' and arsenic was to ascertain whether these two active ingredients would have any improved or, on the other hand, detrimental effect on one another or on the tick.

Results.—The results of these field dipping trials showed that:

(1) The groups of cattle dipped regularly at the 7-day interval were completely protected against infestation of the arsenic-resistant blue tick when dipped in dip-washes containing the suspension-type dip at 'Gammexane' concentrations of from 0·0064 to 0·0034 per cent., and when dipped in washes containing the emulsion-type dip at 'Gammexane' concentrations of from 0·0051 to 0·0025 per cent. This effective control was

attained by the third weekly dipping in two of the three emulsion-type dip-washes used at the 0·0025 per cent. strength, and by the fourth weekly dipping in the suspension-type dip-wash used at concentrations of 0·0064 and 0·0034 per cent. A practical working strength of 0·005 per cent., or 50 parts per million, is indicated and recommended.

(2) The groups of cattle dipped regularly at the 14-day interval, although provided with a good protection against infestations of this tick, were less well protected than those dipped at weekly intervals.

(3) Cattle were not satisfactorily protected when dipped in washes at concentrations lower than 0·0034 per cent. for the suspension type and 0·0025 per cent. for the emulsion type. In no single dipping test, however, did the 'Gammexane' dip-washes fail to effect a marked reduction in the blue-tick infestation of the cattle dipped, be it at the 7-day or 14-day interval, even with the dip-washes used at the lowest concentration of 0·0013 per cent.

(4) The results obtained by the use of composite dip-washes containing arsenic and 'Gammexane' did not show any superiority over those obtained with 'Gammexane' alone at identical 'Gammexane' concentration. The addition of any arsenical dip to a 'Gammexane' dip-wash therefore served no useful purpose, but only increased the cost of dipping as well as incurring the objections associated with arsenical dip-washes.

Observations.—(1) Observations made on the washes in the dipping-tanks and analyses of the dip-wash samples taken indicated that the 'Gammexane' in these washes remained effective against the arsenic-resistant blue tick when used at the aforementioned concentrations.

The first dipping unit started has been operating now for over 9 months and has served for nearly 6,000 head of cattle. The other units have each been used for over 5,000 head of cattle, two others for over 400 head of cattle each, and in each of the rest from 1,000 to 3,000 head of cattle have been dipped.

(2) No adverse effects on the dipped cattle have been noticed; on the contrary they have shown very marked improvement, as indicated below:

The direct effects of the heavy blue-tick infestation on cattle and the indirect effect of the severe drought had made them debilitated and anaemic. The records of owners show that the losses in cattle due to these factors had been over 20 per cent. during the 6 months before these trials were started. But once control of the infestation had been obtained the cattle were able to put on condition and mortality fell to below 2 per cent.

The skins of the dipped cattle showed a characteristic improvement, becoming soft and pliable, with a good sheen.

Cattle with open wounds, provided these were not deep and penetrating, were dipped without adverse effect; in fact, it was found that the dip-wash was beneficial, as the wounds never became fly-struck and healed up quickly. Special observations made on working oxen and milking cows showed that regular dippings did not affect their service or milk yield, respectively, cause any taint or smell to the milk, or affect the teats and udders.

Inclement weather, other than heavy or continuous rain, did not interfere with the regular dipping of the cattle, and at times dipping was carried out in intermittent light coastal rains without any ill effect.

Some cattle have been re-dipped immediately, within an hour of the first dipping, at 5-day, 4-day, and 3-day intervals, without adverse effect.

(3) Throughout the trials there has been no indication that these 'Gammexane' dip-washes have acted as repellents of this blue tick, careful examination of the cattle having shown the presence of the larval stage—an indication that infestation was continually taking place.

2. *The Arsenic-resistant Blue Tick: Infestations on Horses and Goats*

In the western portion of the district a severe infestation was found on horses at four of these experimental units, and a medium infestation was found on goats at two units. The infestation on the horses was general, particularly over the regions of the throat, head, mane, neck, shoulders, and legs. That on the goats was not so severe, but, through rubbing due to the irritation set up by this tick, these goats had a mangy look, with bare patches over neck, brisket, ribs, belly, back, and escutcheon. The main infestation on these goats was due to the larval and nymphal stages, and very few adult engorged females could be found as the goats themselves removed these by biting and rubbing.

Parallel dipping tests with these horses and goats were carried out in the same dip-washes used for the cattle. The results showed that 'Gammexane' dip-washes at concentrations of 0·0064 to 0·0025 per cent. effected control over this tick by the third weekly dipping. The use of these dip-washes improved the appearance and skin of the animals, without adversely affecting either their constitution or the working ability of the horses.

3. *Other Tick Infestations*

In addition to the blue-tick infestation recorded, found on all the cattle in these experimental dipping units, the red tick, *Rhipicephalus evertsi* (Neumann), occurred in all units, the brown tick, *Rhipicephalus appendiculatus* (Neumann), was found in three units on the East Bank, and the bont tick, *Amblyomma hebraeum* (Koch), in two units on the West Bank of the East London district.

On account of the short feeding-time and the predilection sites of the two-host red tick and the three-host brown and bont ticks, and because these 'Gammexane' dip-washes have no repellent action, the basis of effective control was to prevent engorgement of these ticks at any stage. The special measures taken to get this control were hand-dressing of the ears and under the tails with strong concentrations of 'Gammexane' preparations and the regular dipping of a special group of cattle three times a fortnight at the 5–5–4-day intervals. This special group of cattle was taken out of the 7-day group, and the tests conducted on this group were additional to the ordinary dipping procedure carried out at these units for the control of the arsenic-resistant blue tick.

The hand-dressing of the ears with preparations containing 0·1 per cent. 'Gammexane' killed off the brown tick at all stages, also the red tick present at the time of application in the larval and nymphal stages, and prevented engorgement for a full week after application. At concentrations of 0·25 and 0·5 per cent. 'Gammexane' the same efficacy as for the 0·1 per cent. concentration was obtained, but engorgement was prevented for 14 days after application.

The hand-dressing done under the tails and around the ani of the cattle with preparations containing 0·1 per cent. 'Gammexane' killed off the adult stages of the brown, red, and bont ticks present at time of application, and prevented any engorgement of these ticks for 5 days after application, whereas the 0·25 and 0·3 per cent. concentrations prevented any engorgement for 7 days after application. The continual voiding of faecal matter by the animal causes a weakening of the 'Gammexane' preparation applied over this area, and accounts for the shortened period of protection afforded these parts when compared with that for the ears.

In the use of these hand-dressing preparations on the ears and under the tails it was found necessary to apply them well into the grooves over the ventral surface margins of the outer ear, and well under the tail, over the anus, and in the female over and under the vulva. It was found that if any parts of these surfaces were not so treated the infesting stage of these ticks would develop on these parts.

The results obtained by the regular dippings showed that for the 5–5–4-day interval there was a rapid reduction, over the bodies, of the infesting stages of the red, brown, and bont ticks, and that no engorgement took place when used at concentrations not lower than 0·0034 per cent. for the suspension-type dip, and 0·0025 per cent. for the emulsion-type dips. Non-engorged to partly engorged adults of all three species, and non-engorged and engorged larval and nymphal stages of the brown tick, present at the time of dipping, were killed by the dip-wash, but the partly engorged to fully engorged adult females, although affected, survived to lay eggs, some of which hatched.

The results of the 7-day dippings showed a reduction and no engorgement of the infesting adult stages of the brown, red, and bont ticks, but the larval and nymphal stages of the brown tick did engorge. At this interval, and to obtain this efficacy, the concentrations of the 'Gammexane' dip-washes had to be not less than the 0·005 per cent. for the suspension-type dip, and 0·0025 per cent. for the emulsion-type dips. No effective control was obtained over infestation of any stages of these three ticks at the 14-day interval.

It is thus apparent that the most effective control of the brown, bont, and red ticks was at the 5–5–4-day intervals of dipping and hand-dressing at the recommended concentrations of 'Gammexane'.

4. *Other Infestations*

Hornfly.—Infestation by the hornfly, *Lyperosia irritans* (Linné), was general on cattle in the East London district and severe in four tank units in the early months of 1945. Controlled dipping tests with 'Gammexane'

washes resulted in a marked reduction by the fourth weekly dipping, and, although still present in small numbers on the 14-day groups of cattle, these regular dippings have maintained an excellent control.

Fleas.—A severe flea infestation on dogs and poultry was experienced in the East London district during the early summer months of 1945. The dog flea, *Ctenocephalides canis* (Curtis), was controlled by weekly dipping at concentration 0·0025 per cent. of 'Gammexane' or by weekly dusting with powders containing 0·1 per cent. The poultry flea, *Echidnophaga gallinacea* (Westword), was controlled by weekly washes at 0·0064 per cent. 'Gammexane' or dusting with 0·1 per cent. powders. No adverse effect on the dogs or poultry was observed.

Lice.—The pig louse, *Haematopinus suis* (Linné), was controlled by dusting with 0·1 per cent. 'Gammexane' powder. The nits failed to hatch after treatment.

Goats.—*Bevicola caprae* (Curlt), the biting louse, and *Linognathus stenopsis* (Burmeister), the sucking louse. A general infestation of these pests was controlled by a single dipping in a wash containing 0·0064 per cent. 'Gammexane'. No adverse effect on the animals was observed.

Sarcoptic mange on goats.—Scrapings of goats in the East London district showed the presence of the mites and eggs of *Sarcoptes scabi* var. *caprae* (Fürstenburg). Three immersion dippings of 800 goats at 8- and 9-day intervals in a 'Gammexane' suspension at 0·0064 per cent. concentration gave complete control. No parasites were found 8 weeks after the last dipping.

Bed-bug.—*Cimex lectularius* in two rooms occupied by native servants were painted with a wash containing 0·25 per cent. concentration of 'Gammexane' and the beds and bedding dusted with 0·1 per cent. 'Gammexane' powder. The rooms have remained bug-free for a period of 4 months.

Fly-infestation of dairy premises.—(1) A light spraying over ceilings, rafters, doors, window-frames, and walls of a 0·1 per cent. 'Gammexane' wash maintained an active control for over 8 weeks. (2) A second application evenly painted on gave a residual control for over 12 weeks.

Summary

'Gammexane' is the name given to the insecticidally active isomer of hexachlorocyclohexane.

Spraying tests conducted against the arsenic-resistant blue tick indicated that 'Gammexane' could be used effectively. The results of dipping reflect the work done at 11 tank units carrying 2,400 head of cattle. For the 10 months of test more than 36,000 head of cattle, as well as 200 horses, 3,000 goats, and 50 dogs, were dipped.

These tests showed that 'Gammexane' at concentrations as low as 0·0025 per cent. could be used to effect control over this arsenic-resistant blue-tick infestation on cattle, horses, and goats, provided dipping at a 7-day interval was regularly carried out. A working strength of 0·005 per cent. is recommended as being efficacious and safe.

Composite dip-washes, containing prescribed strengths of 'Gammexane' and arsenic, proved no more or less effective against the arsenic-

resistant blue tick than dip-washes containing 'Gammexane' only, when used at identical 'Gammexane' concentrations.

The dip-washes used not only maintained their efficacy, but also proved safe, harmless, and of real benefit to all species of stock dipped.

Parallel tests conducted against infestations of the red, brown, and bont tick species indicated that to effect full control hand-dressing was necessary as an additional measure to regular dipping, and that both should be carried out at 5–5–4-day intervals. The hand-dressing material used in the ears and under the tails must contain a minimum 'Gammexane' concentration of 0·1 per cent. for the ears and 0·25 per cent. for the anal region.

Regular weekly dipping of all cattle on a farm in these 'Gammexane' dip-washes also effected control over hornfly.

Fleas on dogs and poultry were effectively controlled by weekly washings in 'Gammexane' washes of 0·0064 per cent. concentration or weekly dustings with a 0·1 per cent. 'Gammexane' powder.

Lice on goats were effectively controlled by a single dipping in a 'Gammexane' wash of 0·0064 per cent. concentration, and on pigs by a single application of a 0·1 per cent. 'Gammexane' powder.

Sarcoptic mange of goats was controlled and eradicated by three dippings at 8–9-day intervals in a suspension-type dip-wash containing 0·0064 per cent. 'Gammexane' concentration.

Bed-bugs in rooms were successfully controlled for over four months by one application of a 0·25 per cent. 'Gammexane' wash to the walls, and a dusting of the beds and bedding with a 0·1 per cent. 'Gammexane' powder.

Fly infestations of dairy premises were controlled for over eight weeks with one single application of a 0·1 per cent. 'Gammexane' wash.

Conclusions

By virtue of its safe, harmless, and beneficial effects on all species of stock dipped in washes containing 'Gammexane' at the prescribed concentrations all the hazards of dipping associated with arsenical preparations have been eliminated.

The effective control by 'Gammexane' of the arsenic-resistant blue tick and the other more important species of ticks, all of which are transmitters of dangerous protozoan diseases, will enable stockowners to cope successfully with these infestations. Its general efficacy against many of the other more important ectoparasites, such as lice, *Sarcoptes*, fleas, and hornflies, makes this new insecticide an all-in-one product meeting the needs of the South African stockowner.

All these important factors, taken together, make 'Gammexane' a very safe, very promising, and very powerful insecticide.

(*Received July 2, 1946*)

THE EFFECTS OF CONTINUOUS LINE SELECTION IN TRITICUM-AGROPYRON HYBRIDS[1]

J. M. ARMSTRONG[2] AND T. M. STEVENSON[3]

WITH PLATES 3, 4

Introduction.—In its broad aspects plant-improvement is limited by the range of variability in economic characters in the basic material the plant-breeder has at his disposal for selection. In self-fertilized, old-established varieties this variability is slight; cross-fertilized crops with the individual plant-components in a highly heterozygous condition afford better opportunities for selection; but frequently, as an initial step to obtaining diversity of material, the breeder must resort to hybridization of related varieties and species. Sometimes it is possible to create still greater diversity of characters by hybridizing distinct genera. Whilst this leads to the obvious advantages of securing new plant-forms combining characters hitherto distinct, difficulties, such as cytological instability, must frequently occur.

Since 1930 extensive investigations have been conducted in hybridization of Triticum with grass genera, particularly Agropyron. The feasibility of these wide crosses was originally demonstrated by U.S.S.R. scientists, and breeding programmes are well under way there as well as in Canada, United States, South Africa, and Australia. Although no commercial varieties are as yet in general distribution, the published results of investigations indicate that in addition to contributions to our fundamental knowledge of the Gramineae in respect to such subjects as phylogeny, cytology, and genetics, the practical results in prospect have justified past efforts and are an encouragement to additional work.

Morphologically the two genera bear a general resemblance in growth-habit and spike characters. They differ in the major character of perennialism, which is the rule in the Agropyron spp., whilst annual or winter annual habit holds in the wheats. Many Agropyron spp. are stoloniferous, a character that does not occur in wheats. In general, Agropyron spp. are more resistant to disease than wheats.

Cytologically both genera consist of a polyploid series of species with 7 as the basic chromosome number. In Agropyrons this series extends from a diploid form of *A. cristatum* (Fairway $2n = 14$) to the decaploid species, *A. elongatum* ($2n = 70$). In Triticum polyploidy is not quite so extensive, containing a few diploid species, such as *T. monococcum*, several tetraploids, and hexaploids. The hybridization studies between the genera indicate that tetraploid and hexaploid wheats will cross with at least 4 species of Agropyron, *A. elongatum*, *A. glaucum* (*A. intermedium* is regarded as synonymous), *A. trichophorum*, and *A. junceum*.

[1] Contribution from the Division of Forage Plants, Dominion Experimental Farms, Ottawa, Canada.

[2] Cytologist, Division of Forage Plants, Ottawa, Canada.

[3] Dominion Agrostologist.

Literature review.—Since the literature on Triticum-Agropyron hybridization is already becoming extensive it will be sufficient to refer to papers which constitute good reviews of the work to date. White [1], Johnson [2], and Smith [3] have summarized the successful crosses and attempted crosses that give a fair clue to the compatibility of wheat and Agropyron spp. In general, all investigators were able to cross *A. glaucum* and *A. elongatum* with any hexaploid or tetraploid spp. of wheat. *A. trichophorum* and *A. junceum* crosses have been reported less frequently, and owing to F_1 sterility breeding work has progressed no farther with these crosses. Tzitzin [4] alone has reported a cross between *T. durum* and *A. repens*.

Peto [5] and Vakar [6] have studied the F_1 meiotic behaviour in the hybrids. From the pairing relationships it could be inferred that one set of 7 chromosomes was common to both genera. The low frequency of bivalents and high number of unpaired univalents observed helps to explain the low fertility in first-generation hybrids.

Peto [7], Peto and Boyes [8], Peto and Young [9], and Armstrong and McLennan [10] have reported on the production of amphidiploid hybrids. Sterile hybrids were made fertile by doubling the chromosome number by the use of colchicine.

The latest available report by Tzitzin [4] outlines the encouraging progress that has been made in the U.S.S.R. Armstrong [11] has made a report on the work in Canada for the period 1935–45.

Aims and objects of breeding work.—Apart from fundamental research this hybridization work has certain practical objectives which have varied in different countries. In the U.S.S.R. the aim has been to create perennial wheat equal in milling and baking quality with our best annual forms; at the same time they are utilizing annual and winter annual derivatives to fit special environments. In Canada we have aimed at obtaining new forage grasses of good seed-size which could be readily established under drought conditions. It is also of some importance that perennialism be combined with a high degree of winter hardiness. In other areas such as the western U.S.A., South Africa, and Australia winter hardiness is not so important in the hybrids, but they must possess a high degree of drought-resistance.

Although we do not discount the possibility of obtaining a useful food-plant, climatic conditions in our wheat-growing areas of western Canada make it doubtful whether continuous wheat-cropping with a perennial species would be either feasible or desirable. The usual practice is to store up moisture-reserves by means of summer fallow and crop every second or every second and third year. There is little doubt that perennial wheat would be subject to the same limitations as grain sown annually, and after one good crop the succeeding years would yield light returns. Treated as grass subject to good pasture management the returns would be light but uniform, the soil would not be subject to wind-erosion, and organic plant-fibre would be restored to the soil.

In the present paper some hitherto unpublished results are given dealing with advanced-generation lines that were produced by line breeding and selection.

Depth-of-seeding test.—To obtain information on seed-size in relation to depth of planting, in the winter of 1944–5 we conducted an extensive experiment in the greenhouse on a comparison of the emergence of hybrids, wheat, and three Agropyron grasses when sown at varying depths. Such an experiment does not duplicate field conditions, but it does permit the control of such factors as planting depth, moisture, and physical condition of the soil. The results from the limited amount of material tested can then be applied to the wide range of material in the process of selection. Table 1 summarizes the materials, methods, and analysed results.

TABLE 1. *Percentage Emergence of Wheat, Grasses, and Triticum-Agropyron Hybrids sown at Varying Depths*

Variety	Depth sown							Av. all depths	Germination per cent. at 0·5 in.	Wt. per 1,000 seeds (gm.)
	1·0 in.	1·5 in.	2·0 in.	2·5 in.	3·0 in.	3·5 in.	4·0 in.			
Kharkov	100	100	95	97	84	50	22	79	100	33·2
Thatcher	97	95	97	96	87	54	43	81	95	25·5
Vernal	92	91	90	87	74	69	50	79	95	34·4
A. elongatum	95	85	72	35	12	5	0	43	90	6·3
A. glaucum	94	81	84	65	47	18	6	56	60	7·6
A. cristatum	79	73	55	5	0	0	0	30	55	1·6
S–89	96	94	96	80	43	15	7	62	90	19·5
S–42	81	90	94	89	83	51	40	75	95	26·6
S–91–W	95	95	94	83	55	30	10	66	100	19·7
S–91–H	92	87	73	78	58	21	5	58	85	18·5
S–107	90	90	80	74	64	49	24	67	65	20·4
S–147	92	92	89	85	59	50	35	72	55	20·1
Necessary difference for significance	14·5	14·5	14·5	14·5	14·5	14·5	14·5	5·5	5·0	

Materials (*cf.* Figs. 1, 2, Plates 3, 4).

Kharkov: A winter wheat, used extensively in our crossing work.

Thatcher: A standard spring wheat in western Canada.

Vernal: A tetraploid wheat also used in crossing, and which in combination with *A. elongatum* has given some promising lines.

A. elongatum: A grass parent.

A. glaucum: Another grass parent.

A. cristatum: Standard cultivated grass used in the drier areas of western Canada.

S–89: Kharkov × *A. elongatum*, a fourth-generation line selection.

B–42: (*Minturki* × *A. glaucum*) × *Minturki*—a back-cross in the fourth generation.

S–91–U: Vernal × *A. elongatum* amphidiploid (hulls left on the seeds); S–91–H (hulls removed).

S–107: Turgidum × *A. glaucum* amphidiploid.

S–147: Kharkov × *A. glaucum* amphidiploid.

The plantings were made at 8 depths, ranging from ½ in. to 4 in. at ½-in. intervals. The soil consisted of 2 parts sterilized compost to 1 part sand. Half-gallon glazed pots were used and 100 seeds planted in each, with each pot replicated 4 times. The experiments ran for 25 days from the day of planting until the final count. The emergence at the ½-in. planting was used to calculate the percentage germination, and the

emergence figures at the other depths were weighted accordingly. An analysis of variance was made of the emergence results. The necessary difference for significance can be applied either horizontally or vertically in Table 1.

Wheats: Planted at any depth up to 2·5 in., differences in percentage emergence are not significant; seeded deeper than that, emergence is significantly affected.

Grasses: All three Agropyrons showed a gradual tapering down of emergence from the 1- to the 4-in. plantings. The differences are significant by 1-in. graduations; the limit for *A. cristatum* emergence is 2 in., but 1 in. may be considered the limit for a satisfactory stand of seedlings. The emergence limit of *A. elongatum* is 3 in. with about 2 in. as the maximum planting depth for a fair stand. *A. glaucum* showed some seedlings emerging from 3·5 in. and gave a fairly good stand at 2 in.

Hybrids: B–42, a large-seeded, back-cross derivative, was fully equal to the average of the wheats at all planting depths. It showed no significant decrease in percentage emergence up to the 3 in. planting depth. S–89 emerged satisfactorily up to 2·5 in. and then decreased significantly at the greater planting depths. S–91 showed a fairly similar behaviour to S–89. The hulled sample was lower in germination and showed poorer emergence at the various planting depths than the unhulled sample. It appears that lines that normally retain the hull upon threshing have their viability reduced if closer threshing is followed in the hope of removing the hulls. S–107 and S–147 gave fairly good emergence when planted not deeper than 2·5 in. Beyond that depth there is a definite decrease in emergence.

Correlating the 1,000-seed weights (Table 1) with the corresponding average germination at all depths an r value of $+0{\cdot}92$ was obtained. Referring to Fisher's V. A. Table, where $n = 10$ and $P = 0{\cdot}01$, the value of r for high significance is 0·71. The importance of this correlation is evident in making selections. With the selection of plants of good seed-weight there is a reasonable assurance that such selections will show satisfactory emergence when planted at depths not exceeding 2·5 in., provided that other factors such as moisture-content and physical condition of the soil are not of a limiting nature.

Chemical composition of forage and seed.—The chemical composition of the hybrids with respect to fodder and seed in comparison with standard grasses and wheat gives some valuable comparative data. Obviously if the comparison is distinctly unfavourable to the hybrids, there would be little justification in the efforts expended in producing them.

Table 2 summarizes the analysis of green forage made by the Chemistry Division, Science Service, Ottawa, on material at the hay stage in 1944. The comparison is between 3 amphidiploid lines, the 2 parent grasses, 1 winter wheat, and 3 standard hay species. A duplicate sample of each was analysed. The percentage composition of protein, fibre, and the 2 minerals Ca and P are given in the Table. S–91 is seen to have the highest protein content; S–147 is a little lower, although higher than that of Orchard grass; and S–107 approximates that of Timothy. The differences in fibre-content are very slight. Calcium-content is highest

in S–91 and S–107. It may be concluded that the nutrient values of the amphidiploids are equal to, and in some respects superior to, those of our standard species of hay.

TABLE 2. *Chemical Analysis of Green Forage*

Sample No.	*Year of Seeding*	*Year Grown*	*Description*	*Percentage Composition (dry-matter basis)*			
				Protein	*Fibre*	*Ca*	*P*
42–1	1940	1943	*A. elongatum*	8·02	39·10	0·28	0·39
42–2	,,	,,	,,	9·36	40·37	0·37	0·35
42–3	,,	,,	*A. glaucum*	10·64	37·52	0·35	0·27
42–4	,,	,,	,,	9·55	36·11	0·34	0·29
42–5	1943	,,	Wheat (D.G.C.)	7·36	40·99	0·36	0·21
42–6	,,	,,	,,	7·57	35·81	0·35	0·21
42–7	1942	,,	S–91	11·16	35·02	0·47	0·28
42–8	,,	,,	S–91	11·23	35·40	0·42	0·32
42–9	,,	,,	S–147	8·00	34·95	0·31	0·25
42–10	,,	,,	,,	7·57	35·97	0·32	0·22
42–11	,,	,,	Timothy	9·57	33·00	0·29	0·25
42–12	,,	,,	,,	10·14	34·70	0·39	0·24
42–13	,,	,,	Orchard grass	7·01	41·03	0·27	0·24
42–14	,,	,,	,,	7·33	40·91	0·20	0·25
42–15	,,	,,	Reed canary	8·18	39·46	0·19	0·26
42–16	,,	,,	,,	9·95	38·30	0·28	0·23
42–17	,,	,,	S–107	9·73	37·98	0·49	0·27
42–18	,,	,,	,,	9·50	37·89	0·49	0·22

Some information was also obtained on the relative composition of hybrid grain and wheat. Seed was bulked from several F_3 lines of C.A.N. 1835 × *A. elongatum* and Lutescens 062 × *A. elongatum* and compared with bulked samples of spring and winter wheat and Marquis. The results (Table 3) show that both hybrid lots are higher in protein and the minerals Ca, P, and K than the wheat samples. They are considerably lower than the wheats in carbohydrates and nitrogen-free extract. The fibre-content was also high in the hybrids, although care was taken to see that the hulls were removed from the seed. Obviously the hybrids lack the characteristics necessary for the making of good flour and bread, but do possess high nutritive value as feed grain.

TABLE 3. *Chemical Composition of Hybrid Grain and Wheat*

Material	*Percentage composition*								
	Protein	*Ash*	*Carbo-hydrates*	*Fibre*	*Ether-extract*	*N-free extract*	*Ca*	*P*	*K*
C.A.N. 1835 × *A. elongatum*	25·0	3·1	68·5	3·6	3·4	64·9	0·11	0·68	1·04
Lutescens × *A. elongatum*	27·1	3·6	66·5	3·5	2·8	63·0	0·14	0·67	1·19
Marquis	18·4	1·6	77·5	2·6	2·5	74·9	0·05	0·31	0·74
Spring wheat (average)	16·0	1·8	79·9	2·4	2·3	77·5	0·04	0·45	0·49
Winter wheat (average)	12·5	1·8	83·4	2·4	2·3	83·0	0·04	0·45	0·49

So far the hybrids have not been tested in grazing trials to determine their palatability for various kinds of livestock. In a trial at Saskatoon the parent grass *A. elongatum* was eaten readily by livestock in spite of the rough texture of the leaves. The hybrids in general have smoother, softer leaf-texture than the parent grasses and appear quite an attractive forage.

Perennialism.—The number of factors involved in the inheritance of perennialism is difficult to determine, owing in part to the differences in the severity of winter-killing in different seasons, and in part to the cytological irregularities of the material in the early generations. However, certain conclusions can be drawn by examining the data as a whole.

Table 4 contains a summary of the winter-survival of line selections in successive generations for the 8 winters from 1937–8 to 1944–5. The lines were grouped into 4 categories based on the chromosome numbers of the hybrid combinations:

Tetraploid wheat × *A. glaucum*:
$2n$ of $F_1 = 35$; 60 per cent. of chromosome, Agropyron.
Hexaploid wheat × *A. glaucum*:
$2n$ of $F_1 = 42$; 50 per cent. of chromosome, Agropyron.
Tetraploid wheat × *A elongatum*:
$2n$ of $F_1 = 49$; 71·5 per cent. of chromosome, Agropyron.
Hexaploid wheat × *A. elongatum*:
$2n$ of $F_1 = 56$; 62·5 per cent. of chromosome, Agropyron.

This represents a chromosome series increasing by the basic number 7. With tetraploid wheat × Agropyron having a greater proportion of Agropyron chromosomes in their cells, it might be expected that a higher degree of winter-hardiness would be associated with perennialism in these crosses than in the other two. In the F_1 generation the tetraploid hybrids had a somewhat higher winter-survival than the hexaploid hybrids. Although the number of plants grown in the F_1 generations were fairly small they were tested over a 3-year period, so that the conclusion is fairly sound.

In the F_2 populations one striking feature is the relatively high proportion of perennial plants from all crosses. If this indicates that perennialism is controlled by a series of multiple factors one might expect the F_2 plants to differ inherently from strongly perennial to weakly perennial, depending on the number of dominant genes for perennialism which each plant carries. The survival from winter to winter should show some variation reflecting the severity of the season. Examining the hexaploid × *A. elongatum* F_2 population, where the numbers are fairly large, this is seen to be the case, survival values being more variable than for the F_1 generation.

The F_3 generation may still be regarded as random from the standpoint of perennialism. In every case but the last category of crosses this generation had a greater proportion of annual types than in the F_2 generation. There appears to be a more marked segregation for the character. Some of the F_2 selections obviously contained fewer factors for perennialism than others, so that F_3 lines showed a wide variation in

TABLE 4. *Winter Survival in Triticum-Agropyron Hybrids over 8 Winters at Ottawa*

Year		*Tetraploid wheat* ×A. glaucum			*Hexaploid wheat* ×A. glaucum				*Tetraploid wheat* ×A. elongatum					*Hexaploid wheat* ×A. elongatum				
		Generation			*Generation*				*Generation*					*Generation*				
		1	*2*	*3*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1937–8	A	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4763	..	..
	B	..	..	..	..	..	..	..	..	..	..	..	..	..	..	95·7	..	..
1938–9	A	..	..	..	55	..	..	..	60	347	..	..	..	151	1490	4660	..	..
	B	..	..	..	54·5	..	..	..	100·0	94·8	..	..	..	91·5	87·8	70·4	..	..
1939–40	A	14	395	..	65	19	..	..	52	129	175	..	..	201	1217	2147	1197	..
	B	92·9	95·2	..	96·9	63·2	..	..	98·0	87·6	45·7	..	..	91·5	67·6	75·8	62·5	..
1940–1	A	17	4	30	17	7	29	..	5	248	198	27	..	7	131	1353	2178	..
	B	100·0	75·0	100·0	88·2	100·0	48·2	..	100·0	95·6	90·4	14·8	..	100·0	97·7	96·1	86·6	..
1941–2	A	..	28	495	..	155	194	..	..	..	242	..	..	..	1068	1665	2067	1296
	B	..	82·1	54·5	..	96·1	98·5	..	..	..	49·1	..	..	..	72·8	75·7	74·6	94·3
1942–3	A	..	..	..	..	..	..	86	..	..	..	204	..	..	..	..	325	570
	B	..	..	..	..	..	..	2·4	..	..	..	59·8	..	..	..	..	93·5	61·6
1943–4	A	..	..	..	..	..	2203	790	..	..	..	..	..	..	..	540	968	2715
	B	..	..	..	..	..	61·5	93·9	..	..	..	..	..	..	..	73·5	75·1	64·2
1944–5	A	..	..	..	..	..	..	..	..	..	..	..	1158	..	..	..	..	1668
	B	..	..	..	..	..	..	..	..	..	..	..	97·4	..	..	..	..	98·8
Total	A	31	427	525	137	181	2426	876	117	724	615	231	1158	359	3906	15,128	6735	6249
	B	96·8	94·1	57·1	79·6	92·8	72·6	85·2	99·1	93·8	61·5	54·5	97·5	91·6	77·8	81·7	77·3	79·5

A = Number of plants alive in the autumn. B = Percentage survival.

survival values. This is shown in Table 5 where the distribution of F_3 lines in 2 hexaploid × *A. elongatum* crosses are tabulated according to their percentage winter-survival.

TABLE 5. *Distribution of F_3 Lines in Hexaploid Wheat* × A. elongatum *Crosses with respect to Winter-survival at Ottawa in 1939–40*

Material	*Percentage Survival*											
	0–9	*10–19*	*20–9*	*30–9*	*40–9*	*50–9*	*60–9*	*70–9*	*80–9*	*90–9*	*100*	*Total*
C.A.N. 1835 × *A. elongatum*	1	2	3	2	5	14	9	17	19	9	4	85
Lutescens × *A. elongatum* .		2	4	6	4	6	9	14	23	26	5	99

Owing to cytological irregularities in this material in the early generations a factorial interpretation of segregation ratios would not be justified. But it is apparent on the basis of high survival in the F_2 population and the wide range of segregation in the F_3 lines that perennialism is determined by a multiple-factor series, and that winter-hardiness of the hybrids is conditioned to some extent by the number of dominant genes for perennialism.

In the later generations of F_4 and F_5 survival values (Table 4) are no longer random, since F_3 plants were selected from lines that had a high percentage of surviving plants. This has resulted in a rapid stabilization of the perennial character in the later generations.

It is of interest to compare winter-survival at Ottawa and Saskatoon [1] on comparable material and generations. Taking the case of hexaploid wheat × *A. elongatum*:

	F_1	F_2
Ottawa . . .	91·6	77·8
Saskatoon . . .	71·3	55·6

At Ottawa winter low temperatures of −25° F. not infrequently occur, but a good snow-cover usually minimizes their effects. At Saskatoon not only are the winter temperatures lower but the snow-cover is thinner. A higher degree of winter-hardiness for the survival of these hybrids in the prairie provinces is therefore required.

Variability in Advanced Generations

Morphological characters.—In the crosses involving *A. elongatum* where, due to partial fertility in the first generation, line selection could be resorted to, there has been a continuous reduction in variability for any given character in succeeding generations. Table 6 gives the coefficient of variability in three generations for the three characters, plant-height, seed-weight, and fertility. The material is a line from the Vernal × *A. elongatum* cross.

In many lines the plants are attaining fair uniformity for many spike characters, as illustrated by a group of 10 F_5 selections from a line in the vernal × *A. elongatum* cross.

TABLE 6. *Coefficient of Variability in Successive Generations in the Vernal*×A. elongatum *Cross*

Character	F_3	F_4	F_5
Plant-height . . .	12·5	4·7	4·5
Seed-weight . . .	..	20·7	12·7
Fertility . . .	65·2	39·9	28·7

Certain characters, such as awning, florets per spikelet, seed-shape, and rachis toughness, show scarcely any variability. Others, such as the number of flowering tillers, owe part of their variability to plant-environment. The seed-weight falls within the narrow limits of 23–9 gm. per 1,000 seeds. Fertility, which varied widely in the first generations, shows all plants possessing an excess of 20 seeds per head. Continuous selection has also resulted in comparatively free-threshing samples.

TABLE 7. *Head Notes on Selected Plants in an F_5 Line in the Vernal*×A. elongatum *Cross*

Plant No.	*No. of spikes*	*Awning*	*Spike density*	*No. of spikelets per spike*	*Florets per spikelet*	*Rachis toughness*	*Hulled seeds per cent.*	*Seed-shape*	*Seed-weight (gm. per 1,000)*	*Fertility*
S54–111–101–7– 1	82	Ta	78	17	3	4	82	3	29	20
– 3	40	,,	75	18	3	4	98	3	26	23
– 5	60	,,	66	15	3	4	99	4	27	24
– 8	70	,,	65	18	3	3	98	4	23	32
–10	65	,,	77	16	3	3	94	3	24	28
–12	46	,,	63	16	3	4	88	2	29	20
–35	46	,,	76	17	3	4	98	3	27	30
–37	46	Bs	93	21	4	3	100	3	28	24
–69	31	Ta	78	16	3	3	91	3	29	23
–74	59	,,	70	19	3	3	96	3	26	29

No. of spikes: primary spikes bearing seeds.
Awning: Ta = tip-awned; Bs = beardless.
Spike density: length of 10 internodes of rachis in mm.
No. of spikelets: average of 5 heads, omitting sterile bracts.
Rachis toughness: graded from brittle (1) to tough (5).
Hulled seeds: percentage of seeds with no hulls attached following hand-threshing.
Seed-shape: the length/width ratio.
Seed-weight: weight per 1,000 seeds in gm. (wheat 30 to 35 gm.; *A. elongatum* 6–8 gm. hulled).
Seeds per head (fertility): average of all heads on plant.

Cytological behaviour in line selections.—The meiotic chromosome behaviour in the F_1 crosses were reported on by Peto [5]. This past summer a few F_5 plants from lines of the cross Kharkov×*A. elongatum* and 4 plants from one line in Vernal×*A. elongatum* were selected at random and their meiotic behaviour determined. A composite Table is given below using Peto's data and that of our recent examination.

TABLE 8. *Comparison of F_1 and F_5 Meiotic Chromosome Behaviour in Triticum-Agropyron Crosses (Aver. of 10 P.M.C. per Plant)*

Cross		Chromosome No. (2n)	Associations of Chromosomes							
			1	2	3	4	5	6	7	8
F_1 generation:										
Vernal × *A. elongatum*		49	17·7	8·3	3·0	0·7	0·6	..	..	..
Kharkov × *A. elongatum*		56	19·5	9·5	3·0	1·6	0·5	..	..	..
A. elongatum (parent)		70	2·0	22·1	0·6	3·0	0·2	..	..	0·6
F_5 generation:										
Vernal × *A. elongatum* (from same line)	1	54	2·9	25·2	0·2	..	..	..	..	..
	2	54	1·1	25·0	0·7	..	..	..	..	..
	3	54	1·3	24·7	0·8	0·1	0·1	..	..	..
	4	54	1·0	25·0	0·8	0·1	..	..	..	..
Kharkov × *A. elongatum* (from three lines)	1	55	3·0	26·0	..	..	..	..	..	..
	2	49	3·0	23·0	..	..	..	..	..	..
	3	56	3·6	25·6	0·3	..	..	..	..	..
	4	52	3·3	24·3	..	..	..	..	..	..
	5	58	5·5	25·8	0·3	..	..	..	..	..
	6	52	8·6	21·7	..	..	..	..	..	..
	7	54	7·0	22·6	..	..	..	..	..	..

A. elongatum is a decaploid and is characterized by complex chromosome conjugation with multiple configurations present in every cell, quadrivalents being especially frequent. Peto [5] suggests that the high frequency of multiple associations in the F_1 hybrids is due in part to autosyndesis of the *A. elongatum* chromosomes. From the number of bivalents formed in the F_1 hybrids there appears to be partial homology between at least one set of chromosomes from each parent. The excess of 7 noted in the averages may be attributed to pairing among the *A. elongatum* chromosomes. The frequency of univalents is seen to be quite high.

In the Vernal × *A. elongatum* F_5 generation 4 plants were picked from one line which was quite uniform morphologically. All 4 plants had a *2n* number of 54. This *2n* number is in excess of that of the F_1 generation; 24–5 bivalents were regularly present with 1 univalent and 1 trivalent as the most common additional configurations; an occasional cell was observed with 27 bivalents.

The Kharkov × *A. elongatum* F_5 plants were selected from 3 lines grouped as indicated in Table 8. These lines have not reached the same degree of stability as that of the Vernal × *A. elongatum* line. There is no uniformity of *2n* chromosome numbers and the number of univalents is somewhat higher, especially in plants 7 and 8. Nevertheless, bivalent formation was quite good, indicating that the majority of the chromosomes possessed homologues. Multiple associations of three or more chromosomes were found to be infrequent in this generation, this characteristic of the Agropyron parentage having largely disappeared.

It is apparent that the hybrids are moving towards chromosome stabilization of complete and regular pairing in the successive generations. The Vernal × *A. elongatum* line in question has reached the stage of 25 good pairs and 2 irregular pairs, or it may be regarded as being one

FIGS. 3–10. First metaphase of wheat × *A. elongatum* hybrids. Magnification of figs. is ×1,040. Fig. 3. F_5 plant of Vernal × *A. elongatum*, 1 × I, 25 × II, 1 × III. Fig. 4. F_5 plant of Vernal × *A. elongatum*, 1 × I, 24 × II, 1 × V. Fig. 5. F_5 plant of Kharkov × *A. elongatum*, 1 × I, 24 × II. Fig. 6. F_5 plant of Kharkov × *A. elongatum*, 7 × I, 22 × II, 1 × III. Fig. 7. F_3 plant of (Kharkov × *A. elongatum*) F_1 × Lutescens, 6 × I, 17 × II, 1 × III. Fig. 8. F_3 plant of (Kharkov × *A. elongatum*) F_4 × Lutescens, 7 × I a fragment, 19 × II (one heteromorphic). Fig. 9. F_3 plant of (Kharkov × *A. elongatum*) F_4 × Lutescens, 7 × I, 16 × II, 1 × III. Fig. 10. F_3 plant of (Kharkov × *A. elongatum*) F_4 × Kharkov, 10 × I, 15 × II, 1 × III, 1 × IV.

step from stability. This is an agreement with the increasing morphological uniformity and fertility observed.

Several complementary theories may be advanced to explain the decided improvement in chromosome pairing that has taken place in generations intervening between the F_1 and F_5. The most plausible one would appear to be the recovery of homologues at fertilization. A parallel behaviour may be assumed in the female reduction division to that observed in the male cells, and a certain number of univalents from the fused male and female gametes would find mates, and thus pairing relationships in succeeding generations would gradually improve. A second theory based on actual observations is the continual elimination of gametes, both male and female, carrying unfavourable chromosome combinations. Large numbers of empty abortive pollen grains were observed in the F_1 generation. There was a high proportion of sterile florets in the F_1 and to a lesser extent in the succeeding generations, due presumably to imperfect female gametogenesis. There was a certain proportion of non-viable, shrunken seeds. Plants of low fertility were eliminated in every generation by direct selection. These factors operating together would eliminate plants and gametes carrying unfavourable chromosome combinations.

In interspecific crosses of tetraploid and hexaploid, wheat does not appear to have occurred in this intergeneric cross [12]. The authors found that in the F_2 and succeeding generations the plants rapidly segregate into 2 groups, a large 'decrease' group, in which the plants approximate the chromosome number of the tetraploid parent, and a smaller 'increase' group where the chromosome number approaches that of the hexaploid wheat parent. The plants with intermediate numbers failed to appear in the expected frequency. In the group of 7 Kharkov × *A. elongatum* plants studied here the *2n* numbers are: 49, 52, 52, 54, 55, 56, and 58, giving an average of 53·7, or only 2·3 less than the F_1. The *2n* numbers are all intermediate with none approaching 42 or 70, as an analogy with the wheat cross might lead one to expect.

In the F_1 plants of the hexaploid wheat × *A. elongatum* cross the *2n* number is 56, made up of 21 wheat and 35 *A. elongatum* chromosomes. In the plants studied in the F_5 generation the average *2n* number was 53·7, composed of an average of 24·9 bivalents and 4·8 univalents. Some

TABLE 9. *Meiotic Chromosome Behaviour in the F_1 Plants of the (Kharkov* × A. elongatum*) F_4 × Hexaploid Wheat*

Parents in back-cross		*Chromosome No. (2n)*	*Associations of chromosomes*				
Female	*Male*		*1*	*2*	*3*	*4*	*5*
F_4 parent of K × E 6 and 7	Lutescens	43	7·6	16·9	0·6	..	..
F_4 parent of K × E 1 and 2	Lutescens	42	7·6	15·7	1·0	0·1	..
		45	8·9	18·6	0·9	..	..
F_4 parent of K × E 3, 4, and 5	Kharkov	48	8·2	17·9	0·9	0·2	0·1
		46	7·7	18·3	0·6	..	..

indication of the relative proportions of wheat and *A. elongatum* chromosomes can be obtained from a study of back-crosses.

The F_4 parent plants of the F_5 lines from which plants were taken for cytological study (Kharkov × *A. elongatum*) were back-crossed to hexaploid wheat, either Kharkov or Lutescens. A cytological examination was made of some F_1 plants from this late-generation back-cross. The results are given in Table 9.

Since the back-cross plants represent a new F_1 generation in which no chromosomes have been lost, the chromosome numbers of the contributing male and female gametes can be deduced:

TABLE 10

Chromosome no. in back-cross plant	*Contributing male wheat gamete* (*n*)	*Contributing female hybrid gamete* (*n*)	*No. of bivalents*
43	21	22	16·9
42	21	21	15·7
45	21	24	18·6
48	21	27	17·9
46	21	25	18·3

Of the 21 chromosomes contributed by the male gamete homologues were present for an average of 17·5. In addition there is an increase of multiple configurations as compared with F_5 plants. If we deduct the 7 homologous pairs shown to be present in F_1 hybrids (hexaploid × *A. elongatum*), 11 additional wheat chromosomes found homologues. The residue of unpaired chromosomes would be largely of Agropyron origin. A typical F_5 plant of 54 chromosomes may be considered to be made up of 7 pairs of which the partners are from different parents: 11 pairs of wheat origin, 7 pairs of Agropyron origin, and 4 univalents of undetermined origin.

It would therefore appear that in making selections which incline towards wheat in appearance the proportion of Agropyron chromosomes is also being reduced.

Summary

Crosses involving *A. elongatum*, being partially fertile in the early generations, permitted continuous selection in the direction of desirable types without resorting to back-crossing or chromosome doubling.

By selecting for increased seed-size hybrids have been obtained that show good seedling emergence when planted at depths comparable to that used for wheat. This characteristic should render establishment easier under dry-land conditions.

The chemical composition of the hybrids at the forage stage compares very favourably with that of standard grasses; that of hybrid seed is not equal to wheat for milling and baking, but the seed does possess high nutritive value as feed grain.

The perennial character has been well fixed in advanced generations. Perennialism appears to be conditioned by a multiple series of dominant

genes, and the presence of more or less of this series of genes determines the degree of winter-hardiness.

The variability in morphological characters has gradually decreased in advanced generations. Many lines show a high degree of uniformity for certain head characters.

A comparison of the meiotic cytological behaviour of F_1 and F_5 generations shows that the hybrids are moving towards chromosome stabilization of complete and regular pairing.

The intermediate $2n$ chromosome numbers are maintained in advanced generations with little tendency to revert to parental numbers.

By means of back-crossing it was shown that lines showing a dominance of wheat-like characters also possess a preponderance of wheat chromosomes.

REFERENCES

1. W. J. White, Intergeneric Crosses between Triticum and Agropyron. Sci. Agric., 1940, **21**, 198–232.
2. L. P. V. Johnson, Hybridization of Triticum and Agropyron. IV. Further Crossing Results and Studies on the F_1 Hybrids. Can. J. Res., 1938, C **16**, 417–44.
3. D. C. Smith, Intergeneric Hybridization of Triticum and other Grasses, principally Agropyron. J. Hered., 1943, **7**.
4. N. V. Tzitzin, Distant Hybridization—the Chief Method of Breeding. Breeding and Seed Growing, 1940, **10**, 4–7.
5. F. H. Peto, Hybridization of Triticum-Agropyron. II. Cytology of the Male Parents and F_1 Generation. Can. J. Res., 1936, C **41**, 203–14.
6. B. A. Vakar, Basdarde zwischen Arten der Gattung Triticum and Arten der Gattung Agropyron. Züchter, 1934, **6**, 211–15.
7. F. H. Peto, Hybridization of Triticum-Agropyron. V. Doubling the Chromosome Number in *T. vulgare* and F_1 of *T. vulgare* × *A. glaucum* by Temperature Treatments. Can. J. Res., 1938, **16**, 516–29.
8. —— and J. W. Boyes, Hybridization of Triticum and Agropyron. VI. Induced Fertility in Vernal Emmer × *A. glaucum*. Ibid., 1940, **18**, 230–9.
9. —— and G. A. Young, Hybridization of Triticum-Agropyron. VII. New Fertile Amphidiploids. Ibid., 1942, C **25**, 123–9.
10. J. M. Armstrong and H. A. McLennan, Amphidiploidy in Triticum-Agropyron Hybrids. Sci. Agric., 1944, **24**, 285–98.
11. —— Investigations in Triticum-Agropyron Hybridization. Empire J. Expt. Agric., 1945, **13**, 41–53.
12. J. A. Jenkins and W. P. Thompson, Chromosome Conditions in the Second and Third Generations of Pentaploid Wheat Hybrids. Can. J. Res., 1930, **2**, 162–70.

(*Received August 15, 1946*)

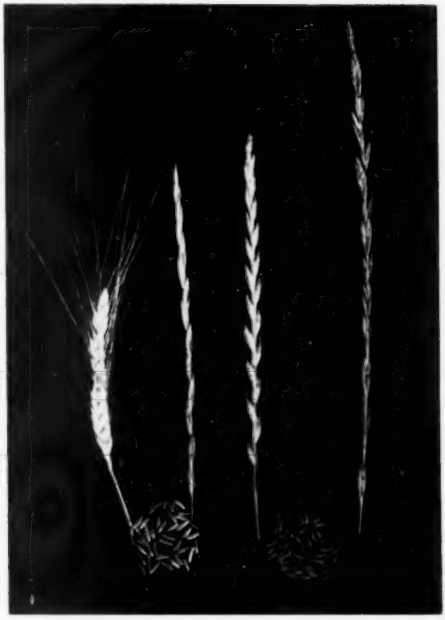


FIG. 1. Heads of Vernal × *A. elongatum* hybrids and parents. Left to right, Vernal head and seed, F_1 hybrid of low fertility with *A. elongatum* characters dominant, F_5 hybrid head and seed, *A. elongatum*

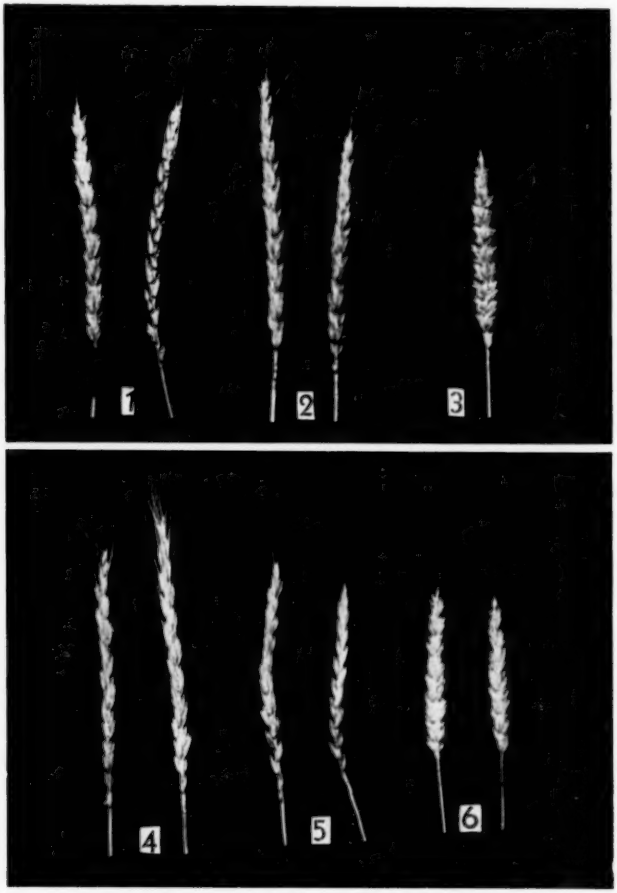


FIG. 2. Heads of Kharkov × *A. elongatum* hybrids, late generation back-crosses and wheat parents. 1. Kharkov × *A. elongatum* F_5. 2. First generation back-cross from (Kharkov × *A. elongatum*) F_4 × Kharkov. 3. Kharkov. 4. Kharkov × *A. elongatum* F_5. 5. First generation back-cross from (Kharkov × *A. elongatum*) F_4 × Lutescens. 6. Lutescens. Note predominance of wheat characters in the hybrids

THE CULTIVATION AND SELECTION OF ROBUSTA COFFEE IN UGANDA

A. S. THOMAS
(*Department of Agriculture, Uganda*)

WITH PLATES 5, 6

Historical.—When Speke, the first European to visit Uganda, arrived at Masaka near the north-west corner of Lake Victoria in 1862, he was presented with 'a cow, sundry pots of pombe (beer), enormous sticks of sugar-cane, and a large bundle of country coffee. This grows in great profusion all over this land in large bushy trees, the berries sticking on the branches like clusters of holly-berries' [1]. Burton and Speke had visited the region south of Lake Victoria in 1858 and had been told of the cultivation of coffee in the country north of the Kagera river and on the islands in the lake, of how the berries were parboiled and dried for chewing, and had seen the coffee brought south by caravans to Kazeh (Tabora), a distance of about 350 miles [2]. Similarly, Grant [3] mentions that coffee was taken from Buddu (the district around Masaka) to markets at Mruli, 100 miles to the north.

Emin Pasha [4] also referred to the trade and cultivation of coffee: he wrote about Unyoro (the region south of Lake Albert) in 1879, 'Coffee drinking is unknown, though the tree grows in the south, and berries are exported in large quantities from Uganda to the north. In addition to tobacco, coffee-chewing is also indulged in in Unyoro and Uganda. The coffee-tree grows in the southern portions of both countries; it resembles the tree I have seen in southern Arabia, only that the leaves of the kind which grows here are larger.'

The old-established cultivation of robusta coffee in a restricted area to the north-west and west of Lake Victoria is of great interest. Robusta coffee (*Coffea canephora* Pierre) is a W. African plant and grows wild in many forests near the Atlantic seaboard, from the Ivory Coast to Angola; but there was no cultivation or use of coffee by W. African natives until recently [5]. The Lake Victoria region is the eastern limit of wild *C. canephora*, but it is the place where this coffee was cultivated before the arrival of Europeans. It is generally agreed that the use of coffee originated in Abyssinia, and it is probable that the use was introduced to Uganda by one of the waves of invasion from the north-east. Wild robusta coffee trees are abundant in some forests to the north of Uganda, and in the adjacent parts of the Anglo-Egyptian Sudan, but little use seems to have been made of their fruit; Emin Pasha, a careful observer and recorder, passed near these forests but did not mention the coffee in them.

Tradition states that the cultivated coffee on the Sese Islands, which are in the north-west of Lake Victoria, and in Buddu, the adjacent part of the mainland, was derived from wild trees in the forests of the mainland. The Kasai Forest in Kyagwe, to the north of Lake Victoria, is

stated to have been an important source of material for planting; but this forest, like all other localities where robusta coffee is now growing wild, is secondary and contains an abundance of soft-wooded trees and large spreading specimens of *Canarium schweinfurthii* and *Chlorophora excelsa*, such as grow on native farms. So it is probable that the coffee is a relict of former cultivation; and it is possible that robusta coffee was introduced to Uganda by man. The smaller species, *C. eugenioides* S. Moore, which is widespread in Uganda forests and which undoubtedly is indigenous, has not been used or cultivated in any way [6].

A ritual significance was attached to robusta coffee. It was used in offerings to the gods and to the spirits. In the ceremony of blood brotherhood, the two beans were taken out of a berry and each man took one, moistened it with his blood, and gave it to the other man to eat. Coffee was used in ceremonial gifts, and when a visitor arrived at a house he was given coffee berries to chew before he was offered other food. No man would plant coffee in his own garden; it was always done by a visitor. Similar uses and beliefs in Bukoba are recorded by Jervis [7], who has suggested that the coffee was first cultivated in Buddu and Kiziba about A.D. 1600 and from there spread southwards to Bukoba.

The methods of cultivation indicated a long experience of the crop. The coffee was not grown from seed but from large woody cuttings; sometimes the cutting was bent, both ends inserted in the ground, and both ends would root. When Emin Pasha asked for small coffee plants he was surprised to receive 'a bundle of dry branches, about a yard and a half or two yards long', for he did not realize that that was the usual planting material. In consequence of this vegetative propagation there still exist groups of old trees so much like each other that they appear to be clones; one group on Bukasa Island is said to have supplied coffee regularly to the Kabaka Mutesa, who died in 1884. The coffee was planted in the banana gardens, near the dwellings, and was trained to make large spreading trees; some were nearly 15 ft. high and 25 ft. across (Pl. 5, fig. 1). Owners of large trees were proud of them, and those which bore heavily were called *Nalongo* (mother of twins), a title of honour among the Baganda.

Development

Early reports on the development of Uganda mention the indigenous coffee industry as a possible source of exports. £842 worth of coffee was exported in 1902, mainly from the Sese Islands; but little was done to encourage new planting. Arabica coffee was introduced in 1900 and because of its more highly priced bean was considered superior to robusta coffee; it was distributed to Africans and, when European estates were opened up on a considerable scale from about 1910 onwards, arabica coffee was largely planted on them.

The Department of Agriculture continued to make trials of robusta coffee, and as early as 1916 the Director wrote: 'In the more humid parts of the Protectorate, the life of the Arabian coffee tree is very short, so that *C. robusta*, which is indigenous, will probably be more largely cultivated, as its yield is both large and sure' [8]. Samples of robusta

coffee were sent to England and, as the beans of a Toro variety received a good report, seed of the best tree (No. 9) was raised by Maitland to form plots from which seed was distributed. This Toro coffee was vigorous in growth, erect in habit, and precocious in fruiting (Pl. 5, fig. 2); it was probably derived from the wild coffee in the Itwara Forest, which has these characters [6]. Selection of trees with bold beans was continued by Liebenberg and Snowden; they worked mostly on trees of erect types, both among the progeny of Maitland's No. 9 and in the young plots on native farms.

Although there were large areas of arabica coffee on European estates, the crop was not much developed by Africans in Buganda, and by 1918 it was evident that the production was decreasing. Therefore in 1923 after some discussion it was decided to distribute robusta-coffee seedlings to Africans in some districts. Seedlings of the erect 'No. 9' type were sent out in large quantities; for example, when the inhabitants returned to the Sese Islands in 1920–1 after the islands had been evacuated for 12 years to eradicate sleeping sickness, 125,000 coffee seedlings and 280 lb. of seed were supplied to them.

Robusta coffee proved to be more of a success on native farms than was arabica coffee, but it was not completely satisfactory. The plots of the 'No. 9' type on the Sese Islands soon became unhealthy and their stems were crowned with short primary branches bearing yellowish leaves but no crop. Yet at the same time the old spreading trees, which had survived in the forests covering the abandoned farmlands, continued to be in good health and to fruit well, although it had been considered that these old trees were of such a poor type that they should be removed when the 'No. 9' type was introduced to the Sese Islands.

Examination of the coffee on the Sese Islands in 1932 disclosed:

1. That all the soil was acid and leached, very poorly supplied in bases. One reason for the survival of the old trees was that they had been planted near houses, in places where nutrients had accumulated. Plots of coffee at a distance from the houses died back after a few years; their stunted growth, the yellowing of the leaves, and the fact that shaded bushes remained healthy—all these points suggested that nitrogen deficiency might be the main cause of ill-health. Most of the soils on the mainland were richer than those on the Sese Islands, but the same symptoms were to be seen in plots of robusta coffee which had suffered from overcropping or from invasion by couch grass (*Digitaria scalarum*).

2. That the type of coffee with small leaves and a spreading habit was more hardy than the 'No. 9' type, with its large leaves and erect habit. Many forms of wild robusta coffee, so different that they have been given specific names, were to be found in Uganda forests [6], but the trees which had survived on native farms all tended to have small leaves and a spreading habit (Pl. 6, fig. 1).

Most of the old trees unfortunately had very small beans, a character which was an advantage when coffee berries were used locally for chewing, but which was a great disadvantage when the beans were exported. Maitland [9], who had selected the 'No. 9' type, had also drawn attention

to the advantages of the spreading types; he planted some on the Kampala Plantation, but they all had very small beans. However, when a search was made among the native farms on the Sese Islands and on the mainland to the west and north of the lake, some trees were found with beans above the average in size, making a product readily acceptable to the export market. Therefore from 1934 onwards the seedlings raised for distribution to Africans have been of the large-seeded spreading types.

The area of robusta coffee on European and Asian estates has also increased greatly since 1925; as the arabica coffee died back, it was interplanted and replaced with robusta coffee. Erect forms of robusta coffee were used, some of the 'No. 9' type and some derived from an importation of Java seed by the Mabira Forest Rubber Company. Robusta coffee proved to grow and crop quite well when planted among Hevea rubber which, under Uganda conditions, casts only a light shade; heavier yields were obtained when robusta coffee was planted by itself in the open, but sometimes the crops were excessive and severe dieback ensued. The single-stem method of pruning was tried at first but was soon found to be less suited to Uganda conditions than was multiple-stem pruning which ensured a succession of young stems from the base; this finding was supported by records from departmental experiments. And the planters found that manuring with cotton seed was of great benefit to robusta coffee, especially to plots on poor soil or that had suffered through overbearing.

Selection

The large and increasing demand by Africans for coffee plants made it necessary to supply considerable quantities of seedlings; it was not feasible to attempt vegetative propagation on a scale to satisfy the demand, although the old trees on native farms showed that plants grown from cuttings would be vigorous and productive. Grafted bushes of robusta coffee had been less satisfactory; they were tried first by Maitland in 1917 at Kampala and, on a larger scale, by Snowden in 1930; many of the trees grew well at first, but after a few years one after another died off suddenly through incompatibility between stock and scion.

Selection of coffee trees was based on vigour, yield, and size of bean. Vigour was secured by paying attention only to trees older than 10 years, for those which survived beyond that age should be well suited to Uganda conditions; many of the trees were much older—one selected tree on the Sese Islands, whose trunk was a metre in circumference, died recently at an age of 120 to 150 years, which appears to be about the limit of life for robusta coffee in Uganda and Bukoba. Yield was assessed by paying repeated visits to the trees over a period of years and noting the crop borne on the trees. The shape of the trees was also used as a measure of the cropping, for a very spreading habit was usually caused by the weight of cherry which had pulled down the branches. Bean-size was assessed by eye and by weighing small samples prepared in the laboratory.

It was difficult to arrange the collection of seed from the selected trees scattered over the Sese Islands and the mainland near the west and north shores of Lake Victoria; and it was by no means certain that the progeny of all the trees would be satisfactory. Therefore progeny rows of some of the best trees were planted at the Kawanda Experiment Station in 1935; the seedlings were spaced at 15 ft. sq., trained to spread, and until 1942 were interplanted with untrained temporary trees. On an adjacent plot there were planted progeny rows of selected erect robusta coffee trees at a spacing of 12 ft. sq., pruned to give a succession of stems, and interplanted until 1940 with temporary bushes.

Individual tree records have been kept by weighing the cherry as it was picked; as some coffee ripens at Kawanda during most months except April and May, the end of March has been selected as the end of the season. Yields of clean coffee have been assessed by dividing the weight of cherry by 5, a figure which gives a slight under-estimate.

Yields of clean coffee in lb. per acre from Kawanda plots planted in 1935

Season	*Erect*	*Spreading*
1937–8	420	150
1938–9	560	220
1939–40	2,100	1,530
1940–1	590	540
1941–2	2,380	1,800
1942–3	1,520	1,300
1943–4	1,200	1,470
1944–5	63	95
1945–6	1,860	2,380
Average for 7 seasons (1939–46)	1,390	1,300

These figures show the high yields of selected robusta coffee growing on the slightly acid red earths common in Uganda, although there are several blank places on the plots caused by root-disease (*Armillaria mellea*) and by house sites; for the coffee was planted on land which had been under native farms and which had not the advantage of a fallow under elephant grass to restore its fertility. The plots were mulched with elephant grass in 1935 and 1936, but have not been manured. Cultivation has been reduced to mere removal of weeds to avoid disturbance of the superficial mat of feeding-roots [10]. The Kawanda rainfall usually is well distributed but is light; the average for the 7 years 1939–45 was 43·88 in. (1,113 mm.), and there was a bad drought in 1944, when only 31·07 in. (790 mm.) of rain was recorded.

Even under such dry conditions the yields were much greater than those reported from Java [11], where 9·3 q./ha. was considered a very satisfactory estate yield. The Kawanda yields were also heavier than those reported by Poskin [12] from the Belgian Congo, where a marked tendency to reduction in yields was shown from the age of about 6 years onwards.

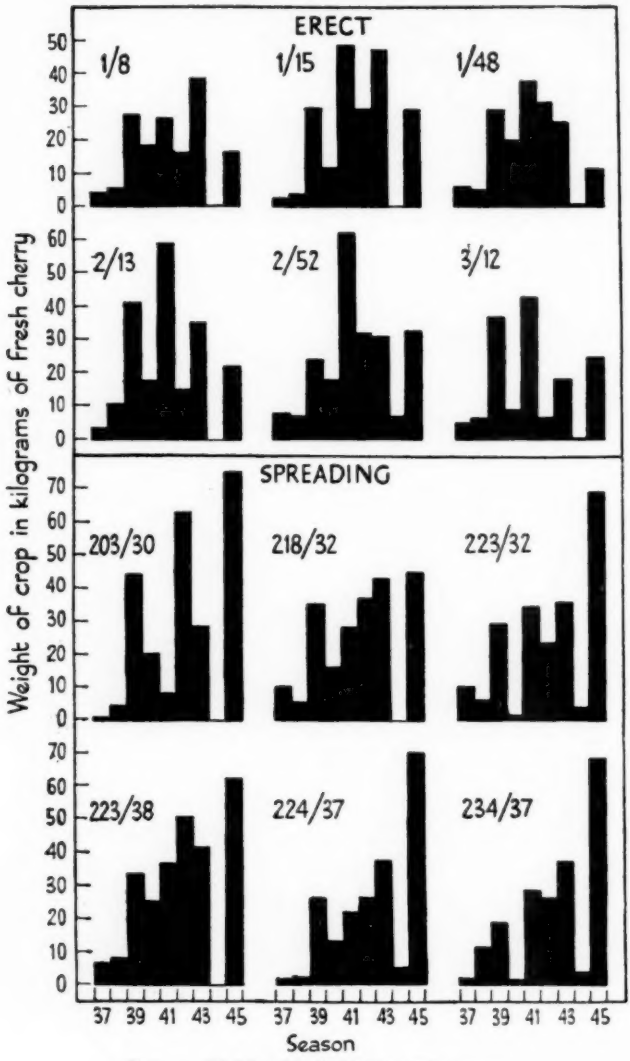


FIG. 1. Fields of individual coffee trees.

The plot of the erect types at Kawanda also reached a peak of yield when 6 years old, but the plot of spreading types has given its largest crop—over a ton of clean coffee per acre—when 10 years old. Individual records of 6 of the most productive Kawanda trees of the erect type, and 6 of the spreading type, are shown in Fig. 1. The diagram shows that some trees exhibited a marked tendency to biennial or triennial bearing.

Most of the erect trees reached a peak of production in 1940 or 1941, when they were 5 or 6 years old; the spreading trees have given their largest crops to date in the 1945 season, when they were 10 years old. All the trees suffered from the 1943–4 drought, and gave poor crops in

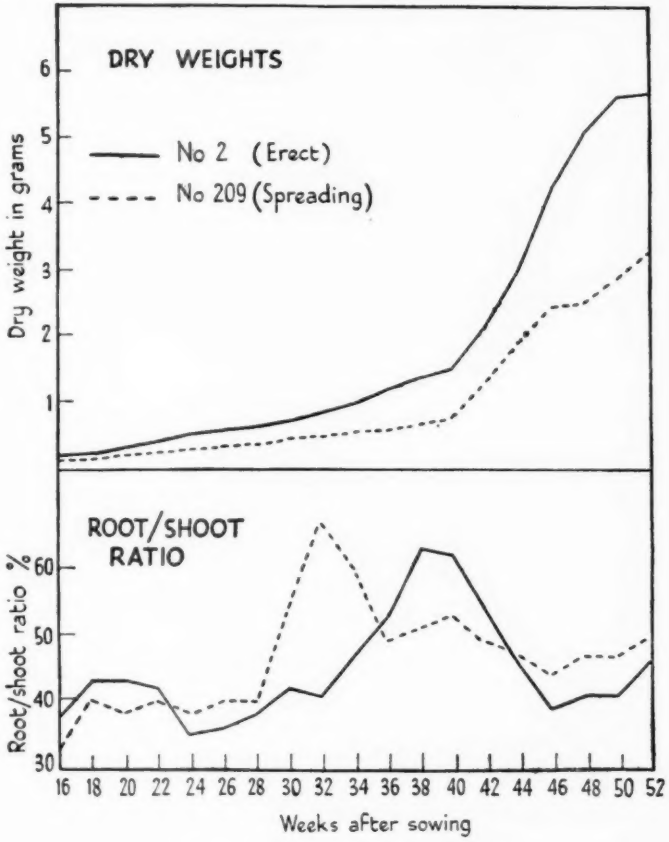


FIG. 2. Growth of coffee seedlings.

1944; the erect trees recovered in 1945 but did not give large crops, whereas some of the spreading trees bore as much as 60 or 70 kg. of cherry, corresponding to 25 or 30 lb. of clean coffee—nor do they seem to have reached their maximum, for some of the old trees in native farms give larger crops than this. As was expected, the plot of erect trees gave the larger yields in the first few years, but since 1943 the plot of spreading trees has been the more productive, and there is not much difference between the average yields—1,390 lb. and 1,300 lb. of clean coffee per acre per annum—for the 7 years since the plots came into full production.

It was difficult to understand why the spreading types should prove in the long run to be more vigorous than the erect types. The weights of seedlings of the two types confirmed the impression that the spreading types were more slow growing (Fig. 2) and this was also shown by measurement of the plants for 3 years in the field.

As a general rule, in the neighbourhood of Kampala the main crops of erect robusta coffee ripen in the dry season of January and February; the main crops of the spreading trees ripen in November and December. Measurements of coffee branches on the Kampala Plantation showed the

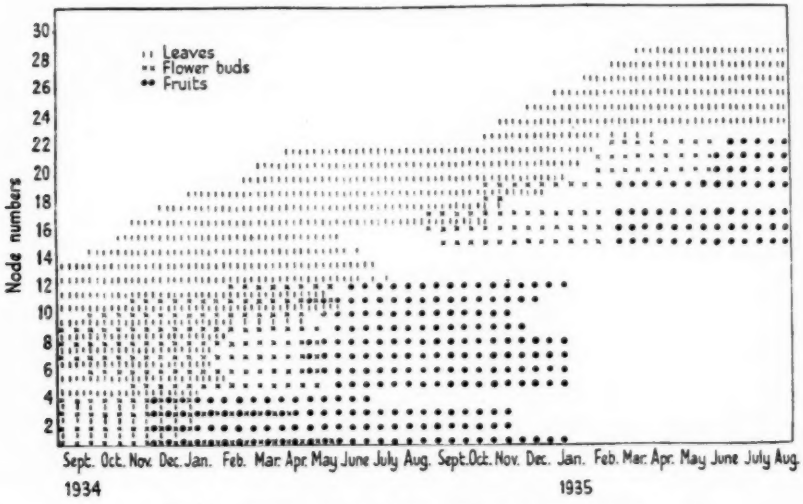


FIG. 3. Growth of a robusta coffee primary branch.

importance of the time of ripening of the fruit on the vegetative growth of the trees. Fig. 3 is a diagram of growth by a typical primary branch and shows the production of leaves, flower buds, and fruit over a period of 2 years. The branch continued to grow until April 1934, when a large crop of berries began to develop; when the berries were picked from November 1934 to January 1935, vegetative growth restarted, only to die down in March 1935, when another crop was set. These observations had the unexpected result of showing that fruiting coffee trees made most of their growth in the dry seasons, for that was the time when they were carrying little crop. The amount of fruit was the controlling factor to vegetative growth, and not the conditions of soil or climate: this was shown by other facts: (*a*) young bushes, which had not started to fruit, grew most rapidly in the rainy seasons; (*b*) self-pollinated branches, on which few or no fruits were set, would continue to grow while adjacent branches, on which a heavy crop was set by open pollination, would make no new leaves.

The early ripening of the crop on spreading types was the secret of their vigour in a normal year; the fruit would be removed by the end of December and the trees would have 2 months in which to grow before a new crop of berries was set at the end of February or in March. The later-ripening erect types, on the other hand, would be loaded with cherry until January and February and therefore would have little chance of making new growth before the coming of the rains induced the flowers to open and a new crop of fruit to be set. As might be expected, the trees which yield the largest beans tend to be the latest to ripen. The seed supplied to departmental nurseries, in which seedlings are raised for distribution to Africans, is taken from the trees of spreading types that have large beans; but, in order to eliminate the trees that are late in ripening, the seed is prepared and distributed at the beginning of the harvest. An early crop of coffee suits the economy of African farming near Kampala, as it may be picked before the cotton begins to ripen. It is recommended that both spreading and erect types should be planted on estates, in order to give an extended picking season without too great a bulk of coffee to be handled at one time.

Training

Genetic factors were partly responsible for the good yields from the spreading trees, but both the shapes of the trees and their yields were improved by the method of training copied from that practised long before Europeans arrived in Uganda. When the seedlings were a year old and about 4 ft. high, they were bent over and tied down to a stick, as in the Agobiada method. Suckers arose near the base and a year later these in turn were bent over sideways and tied down, so that there were 4 to 6 radiating stems growing outwards. Erect shoots arising on the upper side of these branches were allowed to grow and, as their weight bent down the original branches, they also sloped outwards and more erect branches appeared on their upper side (Pl. 5, fig. 2). The trees therefore became in form like a fountain, with a constant succession of young branches from the centre. Care was taken that the original suckers were not tied directly outwards, or they would have split off, but they were twisted sideways. No pruning was done: all young branches were retained and, as the crop was harvested, they were pulled outwards.

This method of coffee cultivation is admirably suited to African peasants who have no good tools for pruning, but who have an abundance of fibrous material, such as dry banana-leaf bases, to tie out the stems. Branches on the outside of a coffee stem are liable to break off; those on the inside do not break off and, as coffee wood is so tough, it is possible to climb into old trees and pick the crop without damaging them. It is not necessary to climb into some of the large old trees near Masaka for their branches spread horizontally, so that a tree may be 25 ft. across and not more than 6 ft. high. The training somewhat depresses yields for a year or two, but afterwards leads to an increase in the size of the tree and in the crop: this is shown by the records of the

trained permanent trees in comparison with yields from interplanted unpruned temporary trees of the same strains:

Average yields of trained and untrained trees planted in 1935 at Kawanda (kg. of cherry)

Season	*Trained permanent trees*	*Untrained temporary trees*
1937–8 .	0·6	1·6
1938–9 .	1·1	2·0
1939–40 .	10·5	10·3
1940–1 .	4·8	2·2
1941–2 .	13·9	10·0

By 1942 the permanent trees had so large a spread as to need the full spacing of 15 × 15 ft., and the temporary ones were cut out; more thinning to give a wider spacing will soon be needed. The untrained temporary trees would in time have developed a spreading habit, but they would have had a distinct single trunk near ground-level; their height would have rendered them more liable to damage from wind and the crop would have been more difficult to gather. Poskin [12] found that plots of unpruned robusta coffee gave better yields than those subjected to different forms of pruning; but the method of training used in Uganda before the arrival of Europeans seems to be much better than no training at all; it was tried as a cheaper way of growing coffee than in the form of pruned bushes, but it promises to give as large or larger yields in the long run. The training greatly decreases the cost of cultivation as few weeds can grow in the soil, which is shaded by the thick foliage of robusta coffee and is occupied by the dense mat of coffee roots. Furthermore, the young branches arising in the shady centre of the tree do not fruit very soon and help recovery from the very heavy crops borne on the outside branches.

Breeding

The good yields at Kawanda have justified selection of mother trees by eye but, as might be expected, there have been distinct differences in the habits and yields of the progenies. The average yields from different progenies of selected spreading types (40 permanent trees of each) over a period of 7 years have corresponded from 1,590 lb. down to 925 lb. of clean coffee per acre per annum. It is interesting that the lowest yielding progeny, the only one to give less than 1,000 lb. per acre, was from a small mother tree; both in size and in crop this progeny is below all others in the plot. Poskin [12] has suggested that in the Belgian Congo there may be a negative correlation between vegetative growth and cropping on young coffee bushes; that is not the case in Uganda, where great vigour is needed if unshaded trees are not to suffer from the heavy crops they produce.

Even heavier yields were obtained from some of the progenies (48 permanent trees) of erect types; progenies of selections 1 and 3 gave

yields corresponding to 1,780 lb. and 1,760 lb. of clean coffee per acre per annum over a period of 7 years. These seem to be heavy crops for unmanured coffee, but there is some justification for taking the average of the 40 or 48 trees of a progeny as a basis for estimating potential yields on a larger scale; yet it is fallacious to follow the practice of multiplying the yield of a single exceptional tree to give a figure for yield per acre, for it is obvious that many outstanding trees are more vigorous than their neighbours and occupy more than their share of space both above and below ground.

There has not been sufficient staff to permit routine measurements of growth on all the coffee progenies. The only characters beside yield which have been measured are the weights of cherry and of bean; these have been calculated from samples of 100 typical cherries picked at the height of the crop. As the size of the cherry and of the bean produced by any tree is not constant, but varies according to the amount of crop and the conditions under which it develops, the results from such samples are not very definite, but they have shown that:

(*a*) Usually, the larger the bean, the greater is the proportion of clean coffee to cherry; few of the trees at Kawanda have had an average bean weight less than 0·10 gm. or greater than 0·25 gm.; the weight of clean coffee usually has been between 18 and 25 per cent. of that of the fresh cherry.

(*b*) Even if large samples of cherries or beans are taken from one tree and their individual weights are plotted in a diagram, they do not show a normal distribution.

(*c*) Seedling families, bred by self-pollination of selected trees, show great variation in the average bean-weights of their progenies (Fig. 4): selections 1, 2, 3, and 4 are erect trees, all derived from Maitland's 'No. 9'; but their progenies show great differences in regard both to the means of their bean-weights and to the distributions, which do not seem to be normal. Seedling families of self-pollinated spreading trees—257, 258, 259, and 260—also show irregular distributions of average bean-weights, sometimes resembling those in families from erect trees, e.g. 2 and 258, 3 and 259. Selection 258 and selection 260 were both raised from the same mother tree, yet their seedling progenies are very different, as they show great divergence in the distribution of their average bean-weights.

Robusta coffee is a species in which cross-pollination is usual and in consequence there is often great diversity among the plants growing wild in a forest. Progenies from many forms of the forest coffee have been grown at Kawanda, but none of them has shown as much promise in cultivation as the progenies of trees selected on native farms. Even the cultivated forms have proved to be very heterozygous, as has been shown by the variations of the average bean-weights in their progenies.

The isolation of less variable strains by inbreeding has seemed to be the obvious method of reducing variability. The best trees on the old Kampala Plantation, which has been abandoned, were self-pollinated in 1935 and their progenies were planted at Kawanda in 1937. In the case of 7 selections, illegitimate seedling families from open pollination have

been planted for comparison with legitimate families from self-pollination. It is noteworthy that the yields of progenies from self-pollination have fallen roughly into the same order as those from open pollination; but that in 6 selections out of 7 the trees derived from self-pollination were less productive than those from open pollination. Only in selection No. 4 has the legitimate progeny given the larger yields; and only in this

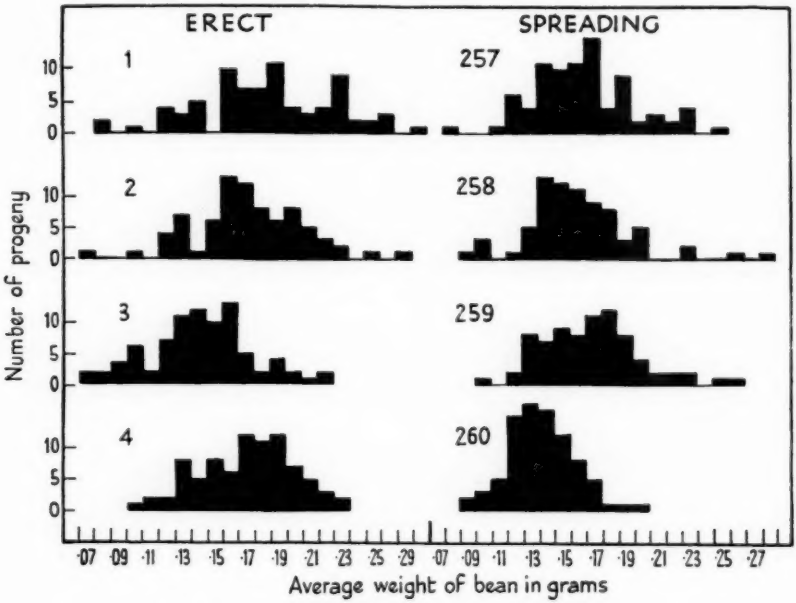


FIG. 4. Average bean-weights of coffee progenies.

case has the average bean-weight from the legitimate trees been much larger than that from the illegitimate trees.

The most outstanding trees in the legitimate families have been self-pollinated and their progenies are being raised, but it will be some years before the value of those progenies is known. If they show much diminution in vigour or in yield, it may be advisable to obtain seed for planting by the cross-pollination of 2 inbred lines. Meantime it is obvious that improvement may be secured by selection of mother trees alone. Illegitimate progenies of some of the best trees at Kawanda were planted in 1941 as randomized rows through trial plots on cultural methods; definite results are not yet available, for the most precocious plots have given only 3 crops, but the progeny of one spreading tree (203/30) has given the best yields in 3 out of 4 replications, and the progeny of one erect tree (3/71) has given the best yields in 5 out of 6 replications.

Variation in robusta coffee is evident with respect to many characters, of which the most important are:

1. *Vigour*. This is of prime importance in selection and, as mentioned above, it is obvious in the case of the large old trees on native farms. With vigour is associated resistance to leaf-disease (*Hemeleia vastatrix*), to which trees are liable when debilitated or when they have overcropped.

2. *Root-system*. When seedlings of different progenies are dug up from adjacent nursery beds there are obvious differences in their root-systems, differences which may be shown by weight (Fig. 2). The diagram of the root/shoot ratio of the seedlings shows two interesting phenomena:

(*a*) In both the erect (No. 2) and the spreading (No. 209) types, there was a marked increase in root/shoot ratio before a great increase in the total weights of the seedlings. This is an indication of the phases of growth to be seen often in equatorial plants—it is obvious in the case of orchids—whereby the roots begin growth before the shoots, and is a matter worthy of detailed study, as it may have a great bearing on the problems of transplantation.

(*b*) Towards the end of the period, the root/shoot ratio of seedlings of the spreading type (No. 209) was consistently greater than that of seedlings of the erect type (No. 2), a factor which also is worthy of study as it may influence the growth and longevity of the trees.

3. *Habit*. Although a distinction has been drawn above between erect and spreading types, yet the two tend to grade into each other for, as some of the erect types become older, the stems they produce are more supple and they tend to assume a spreading habit. It is noteworthy that the most heavy-yielding erect trees have this quality. As the spreading trees get older they also tend to increase in width rather than in height and, as mentioned above, this often shows that the branches have been pulled down by the weight of the crop.

4. *Secondary branching*. Different strains vary greatly in their tendency to form secondary branches on the primary branches. These secondary branches are most desirable, especially on erect trees, as they enable heavier crops to be matured than would be possible with the restricted number of leaves on a primary branch. It is easy to detect plants which will freely produce secondary branches, as they have large bracts among the clusters of flowers.

5. *Leaf-characters*. Specimens of wild robusta coffee collected in Uganda forests have had mature leaves as large as 30×12 cm. and as small as $15 \times 4{\cdot}5$ cm. Similar variation is to be seen in the leaves of cultivated strains, but it is very difficult to measure, as the sizes of the leaves on a coffee plant vary according to the intensity of light in which they have grown and according to the phase of growth, shown in Fig. 3; leaves developed at a time of active leaf-growth are usually much larger than those developed when growth is starting or is slowing down. As a rule, the large-leaved types have fewer veins and a flatter surface than small-leaved types, whose edges are often wavy; large leaves are associated with erect habit, small leaves with spreading habit. The young leaves vary in colour from green to deep bronze; young green leaves exposed to drying winds may be stunted and contorted, whilst young

bronze leaves on adjacent plants develop normally; strains show great difference in their tolerance of exposure, which is often correlated with bronze pigmentation in the young leaves.

6. *Flower characters*. Marked differences are to be seen in the number of flowers per cluster, the length of the stalks, and the number and width of the petals. Even more interesting than the morphological differences in flowers are the genetical ones that control the degree of self-incompatibility; self-pollinated flowers have sometimes given as much as 40 per cent. of fruits, but usually many fewer of them develop.

7. *Fruit characters*. Coffee fruits differ greatly in size, in shape, and in colour. Trees of many erect strains have dark crimson cherries; many of the spreading strains have cherries lighter in colour and one type with orange-yellow cherries is known locally as *Namata*. Considerable variation in fruit colour is to be seen even in legitimate seedlings; the different shades resemble the range of coloration to be seen in apples, and it is probable that, as in the case of apples, many genes are involved in the inheritance of red and yellow pigments. Finally, the beans vary in shape and in size; the irregular distribution of trees when classified according to their bean-weights indicates that several factors are involved in the control of this character. The beans also vary in regard to their liquoring quality, but reports on samples usually state merely that the coffee is readily saleable, and make little distinction between the different strains.

It would be necessary to grow large numbers of seedlings to work out the genetics of robusta coffee, and they would occupy much space. The number of coffee bushes of each progeny shown in Fig. 4 (48 permanent and 46 temporary) was the maximum for which there was space at Kawanda; yet, as the diagram shows, many more would be needed for the analysis of their genetic composition.

Much land is needed even for the selection of high-yielding strains; in order that trees of erect types may show their value, they must be at the wide spacing of 12 ft. square, or 302 trees per acre; with spreading trees at 15 ft. square, there are only 200 per acre. Furthermore, a long time is required for each generation; it is not possible to assess the value of erect types until they are at least 8 years old, so that 10 years are required per generation—1 year to raise the seedling, 8 years for growth and cropping in the field, and nearly 1 year for seed of the next generation to develop. Each generation of spreading trees will require at least 12 years; and it is by no means certain that those trees which are most productive after 10 years in the field will be the most productive after 20 or 50 years; by analogy with results recorded from Java [11], the relative value of the coffee trees at Kawanda may be expected to alter as they grow older.

The limitations of space and time in the breeding of perennial crops such as coffee render it impossible to use a technique which is suited to annual crops. As Cramer [13] has stated in relation to work on robusta coffee in Java: 'The botanist should never let himself be led by figures alone, but should use his brain and eyes for comparing characters and finding out more than the sheet of figures can tell.' Engledow [14] has stated that plant-breeding remains 'a blend of art and empiricism', and

that physiological interpretation of results is needed. 'The secret of the whole matter is how differences in yield are brought about, and only the living plant can reveal this'; the influence of the early ripening of fruit on the vegetative growth of robusta coffee is a case in point. Some good forms of robusta coffee are now growing at Kawanda as the result of visual selection, and it is probable that better ones will result from continued selection and breeding, which may now be based both on observations and on records.

Future Prospects

The cultivation of robusta coffee is expanding rapidly in Uganda. There are estimated to be now about 120,000 acres under the crop on native farms and 6,000 acres on estates. The demand for seedlings from Africans increases each year; and much selected seed is sold to estates, both to plant up new areas and to replace the poorer patches of coffee.

Most of the coffee is cultivated with paid labour, not only on estates, but on native farms as well, and many Africans have large plots. Unfortunately many of these plots, especially those in the Masaka district, have had a short useful life; they have not been mulched or shaded and after the first few heavy crops have been neglected and become infested with couch grass (*Digitaria scalarum*). But the present good prices have led growers to take more care of their coffee, and the improved standard of cultivation, coupled with the long-lived strains that are now being planted, should lead to a great increase of permanent coffee.

The limiting factor to coffee production both for planters and peasants in Uganda is labour rather than land. The Africans have now found out what the Europeans found many years ago—that there is not much profit in cotton production with paid labour, but there is profit in robusta coffee production; that is the reason why coffee is replacing cotton as a native crop in the Masaka district, and it may replace cotton as an export crop in the wetter, cooler areas near Kampala; from the point of view of land conservation under equatorial rainfall it is better to grow permanent tree crops such as robusta coffee than annual crops such as cotton.

Much remains to be learnt about the economy of robusta-coffee production in Uganda; a series of plots planted in 1941 at Kawanda is designed to throw light on this subject, and to show the relative costs and returns of different ground treatments—clean weeding, mulching, manuring, and *Leucaena glauca* cover—of no shade, banana shade, *Albizzia stipulata* shade, and bark-cloth tree (*Ficus* spp.) shade on erect and spreading types of coffee. Interesting differences have been evident from the start, but no definite results will be available for several years, for it is unlikely that the most precocious plots will maintain their lead in yields. Certain points already seem fairly certain; no procumbent cover crops have benefited robusta coffee in Uganda; shade is especially valuable when coffee is growing on poor soil or is subjected to hot, dry spells; the species of *Ficus* seem to be better shade trees than most of the leguminous trees that have been tried [15]; and it seems that spacings of 8 ft. square, which have been used in the past, are too close under the relatively dry Uganda conditions.

The value of manuring has been demonstrated, but careful study is needed to find out the most economical forms and amounts of fertilizer and the best times of application. As mentioned above, debilitated coffee trees appear to suffer from nitrogen deficiency, but wood ashes are known to have a most beneficial effect on them. It may well be that for coffee, as for the vine [16], a high potash-content is necessary for the plant to utilize fully the nitrogen available in the soil; or it may be that the ashes stimulate not only the coffee but also the free-living nitrifying bacteria of the soil. The whole question of the interaction of nitrogen supply, potash supply, and shade requires elucidation.

Exports of robusta coffee from Uganda during the 1945–6 season amounted to more than 20,000 tons and, in conjunction with about 3,000 tons of arabica coffee grown in the country, they make the protectorate the largest producer of coffee in the Colonial Empire. Coffee prices are likely to fall and it is essential that economical methods of culture as a permanent crop—including manuring—should be evolved if Uganda is to maintain and increase its production.

Summary

1. Robusta coffee has been cultivated for hundreds of years near the north-western corner of Lake Victoria, and there has long been a considerable internal trade in coffee for chewing.

2. The old varieties grown on native farms have a spreading habit and small leaves; they prove to be more hardy than the types with an erect habit and large leaves. The spreading varieties ripen their fruit earlier than the erect ones and this character seems to be the reason for their hardiness, as they more easily recover from the strain of cropping.

3. Heavy yields have been obtained on the Kawanda Experimental Station from both erect and spreading types, grown without any manure. The erect bushes reached a peak of production when they were about 6 years old; but the yields of the spreading trees, which have been trained and have not been pruned at all, are still increasing after 10 years.

4. Robusta coffee strains are very variable and appear to be very heterozygous, for there are great differences between the progenies derived from self-pollination of sister trees.

5. The cultivation of robusta coffee in Uganda is expanding rapidly and the country is now the largest producer of coffee in the Colonial Empire, but more intensive study of the crop is needed.

Acknowledgements.—Grateful acknowledgement is extended to all the European planters and African peasants who have helped me by showing their methods of cultivation and by giving seed from their best trees; and to my African assistants who have carried out the routine work in the field and in the laboratory.

FIG. 1. A spreading coffee tree on an African farm near Kampala. This tree was about 20 years old and was not so large as some of the older trees selected

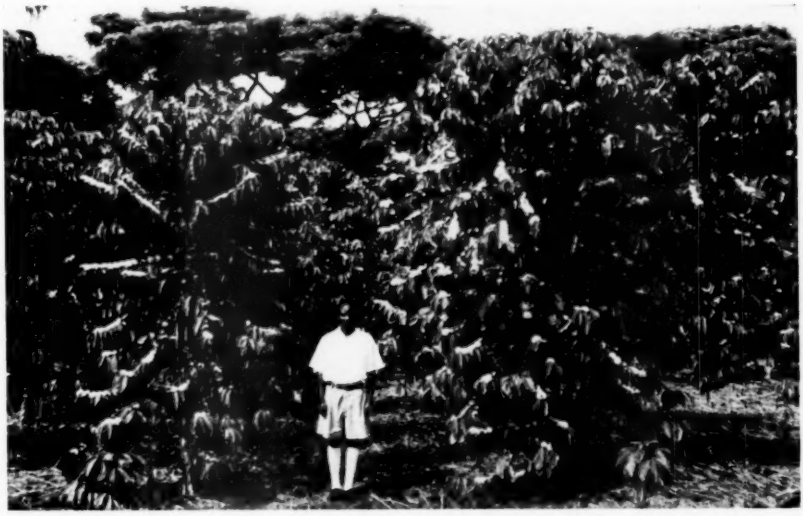


FIG. 2. Erect coffee bushes of the 'No. 9' type, about 10 years old, on the Kampala Plantation

FIG. 1. Leaves and young berries of a selected coffee tree on the Sese Islands

FIG. 2. The base of a spreading coffee tree, 11 years old, on the Kawanda Experiment Station, showing the method of training; in front, a metre rule

REFERENCES

1. J. H. SPEKE, Journal of the Discovery of the Source of the Nile. 1863.
2. SIR RICHARD BURTON, The Lake Regions of Central Africa. 1860.
3. J. A. GRANT, A Walk across Africa. 1864.
4. EMIN PASHA, Emin Pasha in Central Africa. 1888.
5. A. CHEVALIER, Les Caféiers du Globe. 1929.
6. A. S. THOMAS, The Wild Coffees of Uganda. Empire J. Expt. Agric., 1944, **12,** 1–12.
7. T. S. JERVIS, A History of Robusta Coffee in Bukoba. Tanganyika Notes and Records, 1939, **8,** 47–58.
8. S. SIMPSON, Ann. Rept. Dept. Agric., Uganda. 1916.
9. T. D. MAITLAND, *Coffea robusta* in Uganda. Uganda Prot., Dept. Agric. 1926. Circ. No. 14.
10. A. S. THOMAS, Observations on the Root-systems of Robusta Coffee and other Tropical Crops in Uganda. Empire J. Expt. Agric., 1944, **12,** 191–206.
11. M. H. R. LAMBERS, Koffieselectie en Koffie-Plantmaterial. De Bergcultures, 1941, **15,** 45, 1522–32.
12. J. H. POSKIN, La Taille du Caféier Robusta. Publications I.N.E.A.C., 1942. Série Technique No. 31.
13. P. J. S. CRAMER, Early Experiments on Grafting Coffee in Java. Empire J. Expt. Agric., 1934, **2,** 200–4.
14. SIR FRANK ENGLEDOW, The Place of Plant Physiology and of Plant Breeding in the Advancement of British Agriculture. Empire J. Expt. Agric., 1939, **7,** 145–9.
15. A. S. THOMAS, Shade Trees in Uganda and their Relation to the Cultivation of Coffee and Tea. East Afr. Agric. J., 1940, **5,** 287–93.
16. E. VINET, Contribution à l'Étude du Rôle Physiologique du Potassium chez la Vigne. Ann. Agron., Paris, 1942, **12,** 224–39.

(*Received October 12, 1946*)

AN EVALUATION OF THE SELF-TRIPPING CHARACTER IN BREEDING FOR IMPROVED SEED-YIELD IN ALFALFA[1]

T. M. STEVENSON[2] AND J. L. BOLTON[3]

PRACTICALLY all workers who have studied the alfalfa plant have shown that tripping of the flower must occur before fertilization can take place. Carlson [1] and Brink and Cooper [2] have noted exceptions to this rule, but in these cases a relatively low percentage of flowers was reported to set seed without tripping. Armstrong and White [3] have shown that the stigma of the alfalfa flower is covered by a thin membrane which prevents penetration by the pollen tube unless ruptured by tripping, and thus have provided a reasonable explanation of the results of other workers.

Recent papers [4, 5, 6] show that under natural conditions tripping normally is effected by wild bees and that very little occurs from the direct action of wind, rain, and temperature. However, a type of alfalfa plant which has self-tripping flowers has been observed and selected at Saskatoon for several years. Kirk and White [7] originally described these plants but erroneously concluded that fertilization was effected without tripping. Later, Armstrong and White [3] corrected this earlier view and showed that the plants were self-tripping and that structural differences in the wing and keel petals and in the tension of the staminal column distinguished them from non-self-tripping plants. They observed, also, that environmental conditions such as direct sunlight influenced the expression of the self-tripping character. In a group of plants classed as 'high pod-setters' and grown in the greenhouse, they report that 51·3 to 56·5 per cent. of the flowers set pods without manipulation of any kind, whereas in a group of plants described as 'low pod-setters' 4·8 to 8·5 per cent. of the flowers set seed without manipulation.

In recent years at Saskatoon approximately 300 plants selected for high pod-setting under a variety of field conditions have been under close study in the greenhouse during winter months. It has been observed that, except for occasional individuals showing the self-tripping character, only a fraction of one per cent. of the flowers tripped automatically, as an average, and on many plants no automatic tripping occurred. Therefore, it is considered that the group of low seed-setting plants worked with by Armstrong and White was considerably more self-tripping than the great majority of the population of *Medicago media*.

Method of Selecting for the Self-tripping Character

The original selections were taken from a field of the Grimm variety at Saskatoon. Normally, this field sets very poorly and the selected plants were readily observed since they were heavily podded when

[1] Contribution from the Division of Forage Plants, Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Canada.

[2] Dominion Agrostologist, Central Experimental Farm, Ottawa.

[3] Agricultural Scientist, in charge of alfalfa investigations, Dominion Forage Crops Laboratory, Saskatoon.

adjacent plants bore practically no pods. In the fall of the year the selections were brought into the greenhouse and flowered during the winter season. No tripping insects were present and the flowers were not manipulated in any way. A careful record was kept of several racemes of flowers on each plant and the number of pods set was noted. Plants setting a considerable number of pods were classified as highly self-tripping. It should be noted that this technique undoubtedly selected highly self-tripping, highly self-fertile plants and that self-sterile material would not be selected even though self-tripping.

The selected self-tripping plants were used to establish several F_1 selfed progenies. Further selection within lines was carried on where a progeny appeared desirable agronomically, with the result that F_2 and F_3 selfed progenies eventually were established. These selfed progenies were used to provide plants to test the value of crosses between self-tripping plants. In addition, based on the behaviour of their selfed progenies, several of the parental plants were combined under isolation to form 2 synthetic strains.

Experimental Results

Yields of single crosses.—In 1941 one self-tripping plant from each of 6 F_1 progenies was selected and 9 crosses were made. All flowers were emasculated before crossing. In 1942 progenies representing the 9 crosses and a Grimm check were grown in randomized, replicated plots at Saskatoon. Each plot consisted of 1 row with 12 plants spaced 2 ft. apart in the row and the rows spaced 3 ft. apart. Seed-yields were harvested in 1943 and Table 1 is a summary of the data obtained.

TABLE 1. *Seed-yields of Single-cross Progenies from Self-tripping Plants grown at Saskatoon and harvested in 1943*

Hybrid	*Average yield (lb. per acre)*
S–38–$\overline{3}\overline{1}$–1 × S–39–$\overline{5}\overline{4}$–1	636
S–40–$\overline{1}\overline{0}\overline{4}$–1 × S–38–$\overline{3}\overline{1}$–1	490
S–39–$\overline{4}\overline{9}$–1 × S–38–$\overline{3}\overline{1}$–1	452
S–39–$\overline{4}\overline{9}$–1 × S–40–$\overline{1}\overline{0}\overline{4}$–1	449
S–40–$\overline{1}\overline{0}\overline{4}$–1 × S–39–$\overline{4}\overline{9}$–1	385
S–39–$\overline{4}\overline{9}$–1 × S–32–$\overline{1}\overline{9}$–1	362
S–40–$\overline{1}\overline{0}\overline{4}$–1 × S–39–$\overline{5}\overline{4}$–1	285
S–40–$\overline{1}\overline{8}\overline{7}$–1 × S–39–$\overline{4}\overline{9}$–1	213
S–40–$\overline{1}\overline{8}\overline{7}$–1 × S–32–$\overline{1}\overline{9}$–1	106
Grimm Sask. 666 (check)	100

Least significant difference at 5 per cent. point, 131 lb. per acre; at 1 per cent. point, 177 lb. per acre.

In spite of the high error in this experiment the data in Table 1 show that the progeny of single crosses between self-tripping, F_1 selfed plants yielded very significantly more than the check plots in all but 2 crosses. The wide differences between the progeny yield of different crosses illustrate the variation which occurs in the combining ability of different parent plants of alfalfa. For example, S–40–$\overline{1}\overline{8}\overline{7}$–1 appears to be a poor combiner; S–32–$\overline{1}\overline{9}$–1 about average in combining ability; and S–38–$\overline{3}\overline{1}$–1

and S–39–$\overline{49}$–1 good combiners. The plant S–38–$\overline{31}$–1 appears as 1 parent of each of the 3 highest-yielding progenies. The cross between the average and the poor combining plants gave a progeny which yielded only 106 lb. per acre, whereas this yield was doubled for the progeny resulting from the cross of the good and poor combination.

In the winter of 1942–3 a further series of crosses was made between self-tripping plants. Seven F_1 and 6 F_2 selfed plants were used as parents. All parents were unrelated except 5 of the F_2 selfed plants, which all traced back to one original selection. All possible crosses between unrelated parents, 68 in all, were made by hand but without emasculation. In 1943 a comparative yield-test for seed was planted at the Snowden Illustration Station in northern Saskatchewan, where alfalfa normally produces a good crop of seed. All 68 crosses together with Grimm and Ladak checks were included in the test.

In addition to the crosses noted above between self-tripping plants, a series of diallel crosses was obtained in 1942–3 from 13 open-pollinated plants selected for high cross-fertility, but did not possess the self-tripping character. Seventy-seven of the possible 78 crosses in this group were made by hand without emasculation, and the seed together with Grimm and Ladak checks used to plant a comparative test adjacent to the single crosses involving the self-tripping plants.

In both groups of progenies the yield-tests were arranged in a simple lattice-design with 4 replicates. Seed-yields from both experiments were harvested in 1944, and Table 2 presents a summary of the data. The seed-yields given are an average of the progeny yield of all crosses on a particular plant.

The most striking characteristic of the data presented in Table 2 is the very great increase in yield, as compared with standard varieties, which it is possible to obtain in single crosses between selected alfalfa plants. If such increases, or a major portion of them, can be maintained in succeeding generations, then the possibility of improving the seed-yield of the crop is very great. A second but no less important feature of the data is the great difference in combining ability displayed by parent plants in both the self-tripping and non-self-tripping groups. In this connexion it should be stressed that the parent plants in the self-tripping group were all selected from inbred lines of superior seed-yield, and that in the non-self-tripping group all parents were highly cross-fertile. Yet, in both groups there are wide differences in the performance of the crossed progenies of different parents.

It is seen from Table 2 that the best single crosses involving the self-tripping parents were little if any better in seed-yield than the best single crosses between non-self-tripping plants. Thus the best parental material in the non-self-tripping group of plants was found to be equally as high in combining ability for seed-yield as was the best parental material in the self-tripping group. The range in combining ability was essentially the same in both groups of plants.

In order to be utilized in either single or double crosses or synthetic (strain-built) strains, as suggested by Tysdal *et al.* [8], it is essential that a high degree of natural cross-pollination be obtained. Experimental

TABLE 2.[1] *Average Seed-yield of Single-cross Progenies within a Group of 13 Self-tripping and a Group of 13 Non-self-tripping Plants. Unless otherwise noted the Yield for each Parent represents the Average of all Crosses (12 possible) with other Plants within its Group. Grown at Snowden and Harvested 1944*

Self-tripping group			*Non-self-tripping group*		
Parent strain No.	*No. of crosses or checks*	*Av. seed-yield (lb. per acre)*	*Parent strain No.*	*No. of crosses or checks*	*Av. seed-yield (lb. per acre)*
S-38-33-1-4	8	345	S-42-119	12	309
S-38-33-1-1	8	290	S-42-85	12	296
S-40-85-1	12	285	S-42-124	12	281
S-39-49-1	12	269	S-42-179	12	268
S-38-33-1-2	8	254	S-42-105	11	267
S-39-54-1	12	245	S-42-58	12	266
S-40-94-1	12	243	S-42-172	12	258
S-40-104-1	12	224	S-42-60	12	246
S-38-46-1-1	12	213	S-42-182	12	226
S-38-33-1-6	8	210	S-42-99	12	226
S-40-179-1	12	202	S-42-74	12	218
S-40-47-1	12	183	S-42-87	11	171
S-38-33-1-1	8	170	S-42-178	12	166
Grimm	6	166	Ladak	2	168
Ladak	6	162	Grimm	2	129

Least significant difference at 5 per cent. point in lb. per acre.

12 crosses vs 12 crosses	33	12 crosses vs 12 crosses	24
12 crosses vs 8 crosses	37	12 crosses vs 11 crosses	24
12 crosses vs 6 checks	40	11 crosses vs 11 crosses	25
8 crosses vs 8 crosses	40	12 crosses vs 2 checks	45
8 crosses vs 6 checks	43	11 crosses vs 2 checks	45
6 checks vs 6 checks	47	2 checks vs 2 checks	58

[1] Abstract of data presented by J. L. Bolton in a thesis to the University of Minnesota, June 1945, in partial fulfilment of the requirements for the Ph.D. degree.

tests at Saskatoon [4], in the United States [8], and in Argentina [9] have shown that in ordinary, presumably non-self-tripping, alfalfa over 80 per cent. of the seed produced under natural cross-pollination conditions is cross-fertilized.

Although the extent of natural cross-pollination in non-self-tripping plants, particularly when selected for self-sterility as suggested by Tysdal *et al.* [8], is undoubtedly adequate to enable their usage in single or double crosses or in synthetics, there was no information on the extent of cross-pollination of self-tripping plants. An experiment was therefore set up designed to appraise the extent of natural cross-pollination of self-tripping plants by means of the seed-yield of self- and open-pollinated progenies of such plants.

For this purpose 11 high seed-yielding and self-tripping plants were selected from the experiment summarized in Table 1. Open-pollinated seed was harvested from these plants in 1943 and self-fertilized seed in the greenhouse during the winter of 1943–4. Each of the 11 parent plants was clonally propagated as well, and in 1944 a comparative test of parent

clones, open-pollinated seed, self-fertilized seed, and Grimm checks was set up in a split-plot design. Each plot consisted of 21 plants or clones spaced 2 ft. apart in the row, the rows were 3 ft. apart, and each treatment was replicated 6 times except where otherwise indicated. Seed-yields were harvested in 1945 and the data obtained are summarized in Tables 3 and 4.

TABLE 3. *Average Seed-yield of Clones and of Open-pollinated and Self-pollinated Progenies from Eleven Self-tripping Alfalfa Plants. Grown at Saskatoon and harvested in 1945*

Single cross from which parent plants were selected	*Seed-yield (lb. per acre)*			
	Clone	*Selfed progenies*	*Open progenies*	*Grimm check*
S-38-$\overline{3}\overline{1}$-1 × S-39-$\overline{5}\overline{4}$-1 . .	683*	144	201	190
S-38-$\overline{3}\overline{1}$-1 × S-39-$\overline{5}\overline{4}$-1 . .	622†	130	116	185
S-40-$\overline{1}\overline{0}\overline{4}$-1 × S-39-$\overline{3}\overline{1}$-1 . .	590	135	113	190
S-40-$\overline{1}\overline{0}\overline{4}$-1 × S-39-$\overline{5}\overline{4}$-1 . .	585*	229	272	255
S-39-$\overline{4}\overline{9}$-1 × S-40-$\overline{1}\overline{0}\overline{4}$-1 . .	532†	151	216	240
S-40-$\overline{1}\overline{0}\overline{4}$-1 × S-39-$\overline{5}\overline{4}$-1 . .	499	157	160	294
S-40-$\overline{1}\overline{0}\overline{4}$-1 × S-39-$\overline{4}\overline{9}$-1 . .	450*	133	219	221
S-40-$\overline{1}\overline{0}\overline{4}$-1 × S-38-$\overline{3}\overline{1}$-1 . .	414†	211	267	252
S-40-$\overline{1}\overline{8}\overline{7}$-1 × S-39-$\overline{4}\overline{9}$-1 . .	359‡	85	122	253
S-40-$\overline{1}\overline{8}\overline{7}$-1 × S-39-$\overline{4}\overline{9}$-1 . .	299†	136	167	229
S-39-$\overline{4}\overline{9}$-1 × S-40-$\overline{1}\overline{0}\overline{4}$-1 . .	..	228	274	195

Least significant difference at 5 per cent. point for comparison between selfed and open progeny of any one plant or with corresponding Grimm check was 74 lb. per acre.

* Average of four replications; † average of three replications; ‡ average of two replications.

TABLE 4. *Average Seed-yield of the First Ten Clones, Open Progenies, Selfed Progenies, and Checks in Table 3 for the First Two Replicates*

	Clones	*Seed-yield selfed progenies*	*Open progenies*	*Grimm check*
Grand average (lb. per acre) . .	572	155	191	228
Per cent. of clones	100	27	33	40

The averages in this table are based on the first two replications since in many cases clones were not established in the other replications.

Tables 3 and 4 show a very great drop in yield from the parent clones to the open-pollinated and self-pollinated progenies. A considerable reduction in yield of selfed progenies is to be expected [8], but the open-pollinated progenies are little if any better than the self-fertilized progenies. This is good evidence that most of the seed produced under open-pollination was self-fertilized, since, as shown in Table 4 and in most cases in Table 3, this seed did not give progenies equal to Grimm, whilst the parent clones were very superior to Grimm.

Yields of synthetic strains from self-tripping plants.—As noted previously, 2 synthetic strains were developed under space isolation from self-

tripping plants. One of these, designated F.F., was made up of 6 of the best pod-setting selections. The other, designated S.F., consisted of 16 plants including those in the F.F. strain. The seed from these two strains together with a Grimm check was seeded in single-row plots 20 ft. apart, with 6 replications. Seed-yield data for the years 1943–5 are summarized in Table 5.

TABLE 5. *Seed-yields from Synthetic Strains of Self-tripping Plants compared to Grimm Sask. 451. Grown at Saskatoon*

Strain or variety	*Seed-yield (lb. per acre)*			
	1943	*1944*	*1945*	*Average*
Strain S.F.	94	203	146	148
Strain F.F.	69	131	72	91
Grimm Sask. 451	50	120	88	86
Least significant difference:				
5 per cent. point	15	49	32	36
1 per cent. point	21	70	46	51

As is shown in Table 5, the S.F. strain consistently outyielded Grimm in this experiment, but the performance of the F.F. strain was very similar to that of Grimm despite the fact that the parents of this strain were considered to be the best available. A possible explanation of the good performance of S.F. as compared with F.F. is that 16 plants were included in the former as compared with 6 in the latter. Thus the 10 that were considered somewhat inferior plants and included in the S.F. strain may actually have been either less self-tripping or more self-sterile, or both, and either of these factors would have increased the proportion of cross-fertilized seed to selfed seed when compared with the F.F. strain.

Discussion and Conclusions

The general conclusion reached as a result of the data presented in this paper is that self-tripping, self-fertile alfalfa plants are undesirable as a source of breeding material for improving the yield of alfalfa seed. On the other hand, there are considerable possibilities for improvement from the use of non-self-tripping selections. In both classes of material it is vitally important to test crossed progenies in order to determine the combining ability of prospective parent plants.

There are, however, theoretical grounds and some experimental evidence that the self-tripping character may yet be utilized. If self-sterile and cross-fertile types are selected self-fertilization could be largely avoided. At the same time cross-fertilization might be effected by the use of honey bees. A preliminary test at Saskatoon showed that cross-fertilization occurred in alfalfa if foreign pollen was applied 1 hour and possibly longer after tripping where no emasculation was practised. It has been observed also that honey bees repeatedly visit tripped flowers. Thus there remains a possibility of controlling tripping by using the self-tripping character and effecting cross-pollination by an abundance of honey bees.

As stated previously, most of the self-tripping plants at Saskatoon have been selected from poor seed-setting fields and undoubtedly these fields offer the best place to recognize such material. Consequently, since the character may be undesirable, high-seeding selections from such fields should be closely examined for self-tripping. However, non-self-tripping plants obtained from low-yielding fields may be of particular value, since they may be more attractive to tripping and pollinating insects than ordinary alfalfa. Evidence in support of this theory is provided by the results of Vansell [10], who reported wide differences in the sugar-content of the nectar in alfalfa flowers grown under different environmental conditions.

REFERENCES

1. J. W. Carlson, Alfalfa Seed Investigations in Utah. Utah Agric. Expt. Stat., 1935, Bull. No. 258.
2. R. A. Brink and D. C. Cooper, The Mechanism of Pollination in Alfalfa (*Medicago sativa*). Amer. J. Bot., 1936, **23**, 678–83.
3. J. M. Armstrong and W. J. White, Factors influencing Seed-setting in Alfalfa. J. Agric. Sci., 1935, **25**, 161–79.
4. R. P. Knowles, The Role of Insects, Weather Conditions, and Plant Character in Seed-setting of Alfalfa. Sci. Agric., 1943, **24**, 29–50.
5. O. Peck and J. L. Bolton, Alfalfa Seed Production in Northern Saskatchewan as affected by Bees, with a Report on Means of Increasing the Populations of Native Bees. In press.
6. H. M. Tysdal, Is Tripping necessary for Seed-setting in Alfalfa? J. Amer. Soc. Agron., 1940, **32**, 570–85.
7. L. E. Kirk and W. J. White, Autogamous Alfalfa. Sci. Agric., 1933, **13**, 591–3.
8. H. M. Tysdal, T. A. Kiesselbach, and H. L. Westover, Alfalfa Breeding. Neb. Agric. Expt. Stat., 1942, Res. Bull. No. 124.
9. A. Burkhart, Herbage Abstracts, 1937, **7**, 296–7.
10. G. H. Vansell, Alfalfa Nectar and the Honey Bee. Amer. Bee J., 1943, **83**, 106–7.

(*Received August 6, 1946*)

MINERAL COMPOSITION OF MINE-COMPOUND FOODSTUFFS IN NORTHERN RHODESIA

R. S. YOUNG AND A. GOLLEDGE
(*Central Laboratory, Nkana, Northern Rhodesia*)

IT has been recognized for some years that the diet of Africans on the mine compounds is a matter of considerable importance to the large mining companies in Northern Rhodesia. An attempt has been made to provide a better balanced diet than that to which the native is accustomed under village conditions, where the predominant food is maize. This is accomplished by the inclusion in the compound dietary of meat, nuts, vegetables, and fruits, with the object of providing more proteins, minerals, and vitamins.

Attempts to work out a nutritious and economic diet for natives have been handicapped by lack of information on the composition of foodstuffs available in this Territory. Cost considerations practically limit the food for natives to that available locally or in adjoining African territories. Many African foods are not listed in standard food-tables published in Europe or America. In any case the values in the literature could only be taken as approximate, owing to the widely differing soil and climatic conditions. Apart from some investigations on diet and nutrition in India and Ceylon [1], there has been little work published on the mineral composition of foods grown in the tropics. In Northern Rhodesia there are frequently manifestations among the native labour forces of a deficiency of minerals, or at least indications that the intake of them is inadequate for maximum health and efficiency.

Experimental

Large representative samples, 10 lb. or more, of the foodstuffs were secured from the compounds of Rhokana Corporation Limited, Nkana, Northern Rhodesia. Where necessary, any adhering dust or dirt was removed by wiping with a damp cloth. For those foodstuffs where only a portion is edible, this was selected in accordance with native food habits. Though there is a tendency for natives to include in their diet slightly more of the skins, rinds, and coarser portions of fruits and vegetables than Europeans, on the whole there is not a great difference in their eating habits for plant foods. With animal foods, however, the natives are much less fastidious than the whites, and in fact will eat practically all parts of a beast or fish.

The material was weighed, placed in large porcelain evaporating-dishes in a drying-oven, allowed to dry as rapidly as possible at approximately 105° C., and weighed to obtain the percentage moisture as received. The dried material was carefully 'ashed' in a muffle furnace at 550° C., weighed, thoroughly ground, and mixed to ensure a representative sample. Calcium, phosphorus, iron, and copper were determined on the ash by standard procedures. Calcium was precipitated as

oxalate and titrated with potassium permanganate. Phosphorus was separated as ammonium phosphomolybdate and weighed as magnesium pyrophosphate. Iron was isolated and weighed as ferric oxide, and copper was separated from other elements and determined as cupric oxide. In a few cases the copper figures were checked colorimetrically by dithizone or sodium diethyldithiocarbamate procedures [2].

The results of the analyses are given in Table 1. These are reported on both the dry and 'as received' bases, since results obtained elsewhere have sometimes been reported on the dry basis only. We believe, also, in view of the advances in food dehydration, that all work carried out nowadays should include results on the dry basis as well as the 'as received' analyses.

Discussion

On comparing the results in Table 1 with those of analyses quoted in the literature for similar foods in Britain, United States, or elsewhere [3, 4, 5, 6, 7], some interesting conclusions may be drawn.

Calcium constitutes a larger proportion of the human body than does any other mineral element. It is well recognized that dietaries quite adequate in calorific value and protein-content may contain insufficient calcium. It has been reported that the calcium-requirement of the African natives is essentially the same as that of Europeans and Americans [8]. This would indicate a required daily calcium intake varying from 800 mg. for a man to 2,000 mg. for a lactating woman.

As might be expected from foodstuffs grown on the heavily leached soils of Northern Rhodesia, the calcium-content is generally lower than figures reported elsewhere. Of the 30 foods examined, in 29 cases were calcium comparison possible. Twenty were appreciably lower in calcium, 3 were approximately equal, and 6 slightly higher in this element than the same foods reported by others. The calcium ion is one of the least strongly absorbed ions on the iron-aluminium-silica complex which constitutes the fundamental soil particle derived from weathered rocks in most tropical regions. The heavy rainfall, which is concentrated in a few months, consequently leaches calcium readily from soils, and most areas in Northern Rhodesia respond readily to liming.

The high calcium-content of bean leaves, beet leaves, fish, onions, and tripe, as received, is noteworthy. On the dry basis cabbage and spinach are also high in this element, but their low percentage of dry matter places them among the medium calcium-containing foods on the 'as received' basis. In this connexion it must be recalled that the calcium contained in spinach and chard is generally considered to be largely unavailable owing to the high oxalic-acid content of the leaves of these plants.

Some of the vegetables and fruits in Northern Rhodesia are very much lower in calcium than those grown elsewhere. For example, grapefruit, guava, orange, and sweet potato had only a quarter of the calcium reported by other workers, whereas pumpkin and squash had only one-tenth. The very low content of calcium in mealies, the staple food of the African, should be noted. Sweet potatoes and bananas, two other common native foods, are also low in this element.

TABLE 1. *Mineral Composition of Foodstuffs used in the Compounds of Northern Rhodesia*

'As received' basis	*Water per cent.*	*mg. per 100 gm.*				*Dry basis*	*mg. per 100 gm.*			
		Ca	*P*	*Fe*	*Cu*		*Ca*	*P*	*Fe*	*Cu*
Banana	77·1	4·1	16·0	0·33	0·25	Banana	13	53	1·1	0·8
Bean, dried, kidney	8·8	123·3	419·1	5·29	1·44	Bean, dried, kidney	135	459	5·8	1·6
Bean, green	93·4	29·9	79·6	0·76	0·12	Bean, green	450	1196	11·2	2·3
Bean, leaves	87·5	148·2	54·1	6·35	4·76	Bean, leaves	1186	433	50·8	38·1
Beef	61·0	3·6	100·8	0·05	0·02	Beef	9	259	0·1	0·1
Beet, leaves	92·2	148·2	51·9	2·73	0·55	Beet, leaves	1899	666	35·0	7·0
Beet, roots	90·0	19·2	46·1	0·89	0·30	Beet, roots	192	461	8·9	3·0
Cabbage, Chinese	95·3	48·5	16·2	0·76	0·45	Cabbage, Chinese	1032	345	16·1	9·6
Carrot	91·0	32·7	34·1	0·41	0·14	Carrot	363	379	4·6	1·6
Chard	87·4	59·6	13·8	4·26	0·63	Chard	475	110	33·8	5·0
Egg-plant	89·8	5·6	16·1	0·08	0·04	Egg-plant	54	157	0·8	0·4
Fish, dried, bream	8·5	3911·3	2387·1	1·85	1·06	Fish, dried, bream	4275	2609	2·1	1·2
Grapefruit	82·6	5·2	9·1	0·28	0·06	Grapefruit	34	59	1·8	0·4
Guava	..	3·0	5·7	0·86	0·17	Guava	..	..	..	..
Kaffir corn meal	8·5	18·0	204·4	3·71	0·61	Kaffir corn meal	20	223	4·1	0·7
Mango	..	8·9	4·0	0·64	0·19	Mango	..	..	..	..
Mealies, green	62·6	2·1	32·3	0·68	0·15	Mealies, green	6	88	1·8	0·4
Onion	92·3	64·8	34·9	5·07	0·30	Onion	836	500	65·4	3·9
Orange	83·8	10·1	4·8	0·15	0·05	Orange	76	36	1·1	0·4
Paw paw	90·7	35·0	32·9	0·28	0·13	Paw paw	376	354	3·0	1·4
Peanut	6·5	50·4	168·3	6·31	1·10	Peanut	54	180	6·7	1·2
Pepper, green	93·2	7·5	19·6	0·70	0·10	Pepper, green	110	289	10·3	1·5
Pine-apple	94·0	21·1	6·4	0·41	0·07	Pine-apple	352	106	6·8	1·2
Potato, sweet	64·7	5·0	13·7	0·92	0·13	Potato, sweet	14	39	2·6	0·4
Pumpkin	88·4	2·9	28·9	2·35	0·29	Pumpkin	25	249	20·2	2·5
Sausage	57·0	24·6	51·3	3·90	0·69	Sausage	57	119	9·1	1·6
Spinach	92·1	44·4	16·9	2·12	0·39	Spinach	564	214	25·8	4·9
Tomato	96·3	0·8	9·3	0·18	0·04	Tomato	23	251	4·8	1·1
Tripe	80·0	152·1	181·7	0·86	0·45	Tripe	760	909	4·3	2·3
Turnip	91·2	26·3	19·9	0·15	0·16	Turnip	297	224	1·7	1·8

The extremely high contents of calcium and phosphorus in representative samples of dried fish, species of the *Tilapia* genus, compared with the few reported analyses of bream, should be explained. As previously mentioned, our analyses were made on the foodstuffs as customarily eaten by the natives, and the latter consume practically the whole of the dried fish as received. It would be expected, therefore, that the calcium- and phosphorus-contents of this material would be substantially higher than the flesh of the same fish, which alone is consumed by Europeans, and as such reported by other workers.

It is not unlikely that the high calcium- and phosphorus-contents of such articles of food as dried fish, in the form in which they are eaten by Africans, compensates to some extent in mineral metabolism for the lack of milk and other dairy products in large areas of Central Africa.

A point often overlooked in academic discussions of nutrition in tropical countries is the fact that probably a larger proportion of food of both Africans and Europeans is consumed in the cooked state than is the case in temperate regions. This frequently leads to a lower intake of minerals through the discarding of water used in boiling vegetables.

Phosphorus.—As a general rule the phosphorus-requirements of humans are slightly higher than those for calcium [9]. Phosphorus, like calcium, is apt to be critical in mineral metabolism and many cases of a deficiency of this element are reported in medical and veterinary literature. In general, the soils of South Africa are rather low in phosphorus, and much work has been done there on the occurrence and role of this element in animal nutrition. Recommended phosphorus-intakes per day range from 800 mg. for men to 2,000 mg. for lactating women.

Of the 29 foods included in this survey in which comparisons of phosphorus were possible, 23 were found to be considerably lower in phosphorus than other workers have reported, 1 was approximately equal, and 5 were slightly higher. As received, dried kidney beans, fish, Kaffir corn meal, tripe, and peanuts were particularly rich in this element. The dry matter of a large number of foods, such as green beans, bean leaves, beet leaves, cabbage, carrot, onion, paw paw, green pepper, pumpkin, spinach, tomato, and turnip is high in phosphorus. However, owing to the high moisture-content of these plants the phosphorus on the 'as received' basis is intermediate in quantity.

The following foods in Northern Rhodesia contain appreciably more calcium than phosphorus: bean leaves, beet leaves, cabbage, chard, dried fish, mango, onion, orange, pine-apple, spinach, and turnip. This is usually but not invariably in agreement with results obtained elsewhere, but McCance and Widdowson, for example, found, as we did, more calcium than phosphorus in pine-apple, whereas American workers report the reverse for this fruit.

The flesh of fish apparently contains very much more phosphorus than calcium, as indicated by the figures of previous investigators. The dried fish as eaten by the natives of Northern Rhodesia, on the contrary, is much higher in calcium than in phosphorus.

Several local foods were very much lower in phosphorus than the percentages quoted in food tables. Mango, orange, sweet potato, and

spinach contained only about a quarter of the values recorded elsewhere. The relatively low percentages of phosphorus in the staple articles of diet of the native, such as mealies, sweet potato, and banana, are significant.

Iron.—Although iron is probably less likely to be deficient in foodstuffs than calcium or phosphorus, a number of nutritional disorders in various parts of the world respond to iron therapy. Iron and copper are closely allied in their relation to many anaemias and to blood regeneration, and this field is of particular importance in the tropics. Most of the foods containing large quantities of iron are either fibrous and unpalatable or are rather expensive. Recommended iron intakes per day range from 6 mg. for infants to 15 mg. for pregnant and lactating women.

Of the 29 Northern Rhodesian foods for which comparisons are possible, 13 were considerably lower in iron than the figures reported elsewhere, 7 were approximately equal, and 9 were higher than the values of other workers. Iron is much more tenaciously held in the soil complex than calcium and phosphorus, and the soils of Northern Rhodesia contain a higher percentage of iron than do fertile areas elsewhere. It is therefore to be expected that iron would be less frequently deficient in crops in this Territory than some other elements.

The following foods, as received, are high in iron: dried kidney beans, bean leaves, chard, Kaffir corn meal, onion, peanuts, pumpkin, sausage, and spinach. On the dry basis the following, in addition, are good sources of iron: green beans, beet leaves, cabbage, and green peppers. As with the other elements, iron-contents reported by various workers differ considerably, being a reflection of soil, climatic, varietal, and seasonal factors. In most foodstuffs iron occurs in considerably smaller quantities than calcium or phosphorus. Of the 30 local foodstuffs examined, 21 had an iron-content less than one-tenth that of calcium and in 22 the iron was less than one-twentieth that of phosphorus. In only one case, that of pumpkin, did the iron exceed half the quantity of either calcium or phosphorus.

Copper.—It is but comparatively recently that copper has been found to be indispensable in human nutrition. Even yet the copper-content of many foods has not been recorded in the literature. Owing to the frequent use of copper-containing insecticides and fungicides it may be expected that the copper-content of many foods will be quite variable.

In the 27 cases out of the 30 foods in which comparisons of figures are possible the copper-content of Northern Rhodesian foods was appreciably higher in 19 instances, approximately equal in 3, and lower in 5 cases than the results secured by other workers. This is probably not unexpected in a Territory with the vast copper deposits of Northern Rhodesia, where wind and waters must distribute minute quantities of copper some distances from the actual areas of mineralization.

The copper-contents of the local foodstuffs vary, in general, from half to one-tenth that of the iron. In only the onion did we find the copper-content to be less than one-tenth that of iron, and only in turnip was copper equal to iron. Copper was present in a proportion

greater than a quarter that of the iron in 14 cases, equal to a quarter in one sample, and less than a quarter of the iron in 15 instances. We found the following foods, as received, good sources of copper: dried kidney beans, bean leaves, dried fish, and peanuts. The actual dry matter of the following Northern Rhodesian foods is rich in copper: bean leaves, beet leaves, beet roots, cabbage, chard, onion, and spinach. The copper-requirement in human nutrition is approximately one-tenth of that for iron, ranging from 0·5 to 1 mg. per day for children to 1 to 2 mg. for adults. It is apparent, then, that the foodstuffs distributed in the mine compounds are adequately supplied with this element.

Contrary to expectations, the figures for copper reported in the literature did not appear to vary among themselves or differ from our results any more than did the percentages for calcium, phosphorus, or iron.

Comparison of results on 'as received' and 'dry' bases.—In our results on the dry basis, out of 63 comparisons, in 13 cases the differences exceeded 400 per cent., and 7 of these were for iron. On the 'as received' basis, out of 115 comparisons the variations between our results and past analyses equalled or exceeded 400 per cent., 11 times for calcium, 8 for phosphorus, 9 for iron, and in 14 cases for copper. There is, therefore, slightly less variation between the results expressed on the dry basis, but the difference between workers on the dry and 'as received' bases is less than one would expect. It would be expected that mineral composition on the 'as received' basis would vary between plants grown in the rainy season in Northern Rhodesia and in the drier climates and different soils of Europe or America, but it might not be expected that the composition of the dry matter itself would vary to only a slightly lesser degree.

African and 'White' dietaries.—Although this study was begun primarily to shed light on the nutrition of Africans, the results secured should also be of value to whites throughout Central Africa. The latter do not derive as many minerals from the local foodstuffs, since they discard certain portions of vegetables, fruits, meats, and fish which natives eat readily and which contain relatively high percentages of mineral elements. On the other hand, as a rule the Europeans in this Territory have a much more varied diet, from imported fruits and canned or packaged foodstuffs, than natives. The mineral composition of foods is probably just as important for whites in the tropics as for natives, since the climate and other living conditions are not optimum for the white race. In addition, in many areas there is no fresh milk, which forms a large source of some mineral constituents, particularly calcium, in temperate regions.

Summary

A comprehensive study has been made of the principal mineral constituents of mine-compound foodstuffs in Northern Rhodesia.

Comparison with analyses made on similar foodstuffs in other parts of the world indicates that Northern Rhodesian foods are generally considerably lower in calcium and phosphorus than values reported in

the literature. On the whole, iron does not appear to be lower in local foodstuffs, whereas copper in the majority of samples is slightly higher than values recorded elsewhere.

REFERENCES

1. L. NICHOLLS, Tropical Nutrition and Dietetics. London, Baillière, Tindall & Cox, 1938.
2. E. B. SANDELL, Colorimetric Determination of Traces of Metals. New York, Inter Science Publishers Inc., 1944.
3. K. C. BEESON, U.S. Dept. Agric., 1941. Misc. Publ. No. 369.
4. F. W. FOX and L. GOLBERG, S. Afr. Inst. Med. Res., 1944, Publ. No. XLVI.
5. H. J. HEINZ, Company, Nutritional Charts. Pittsburgh, H. J. Heinz Co., 1942.
6. C. D. HODGMAN, *et al.*, Handbook of Chemistry and Physics. Cleveland, Chemical Rubber Publ. Co., 1942.
7. R. A. MCCANCE and E. M. WIDDOWSON, Gr. Britain Med. Res. Council, 1942, Spec. Rept. Series No. 235.
8. H. C. SHERMAN, Chemistry of Food and Nutrition. New York, MacMillan Co., 1941.
9. E. V. MCCOLLUM, E. ORENT-KEILES, and H. G. DAY, The Newer Knowledge of Nutrition. New York, MacMillan Co., 1939.

(*Received April 15, 1946*)

A STUDY OF YIELDS, PREPARATION OUT-TURNS, AND QUALITY IN ARABICA COFFEE

PART I. YIELDS

C. A. THOROLD

(*Plant Pathologist, Department of Agriculture, Trinidad; formerly Plant Pathologist, Kenya Colony*)

THE investigation of a dieback disease affecting *Coffea arabica*, which has been described elsewhere by the writer [1], required an examination of yields and quality. These crop studies provided information of more general interest, and as they were not strictly relevant to the discussion of the disease problem, they are treated independently in this and a subsequent paper.

The crop data were obtained during the period November 1934 to April 1939 on Kapretwa Estate, the property of Major T. H. E. Jackson, in Kenya Colony, which is situated at an altitude of 6,700 ft., in latitude 0·57 N., longitude 34·49 E. The climate at Kapretwa is typically that of the Lake Victoria region, as described by Walter [2], but there is the superimposed local influence of Mount Elgon which rises to 14,000 ft. in the neighbourhood of the estate and is the cause of orographic rains. The rainfall is fairly well distributed throughout the year (Table 1).

TABLE 1. *Average Rainfall (in inches) at Kapretwa Estate, for the 5-year Period (1934–8) of the Investigations*

Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Total*
1·2	2·5	2·3	6·2	7·8	7·1	5·7	5·8	4·8	3·4	2·3	1·5	50·6

The soil at Kapretwa Estate is a red sandy loam derived from volcanic tuff and is markedly acid, with a reaction value of pH 5·9 in the surface 6 in., increasing with depth to pH 4·7 at 4 ft. and below. The content of organic matter and of potash is high, but phosphate tends to be low and there is a marked deficiency of lime (unpublished analyses of local soils).

The spacing adopted over most of the plantation is 9 ft. between the trees, on the triangular system, giving 623 trees to the acre. During this investigation the coffee was grown on the multiple-stem system, in which extension-growth is unlimited during the whole or part of the pruning cycle. Thus, since the coffee plants may attain considerable size and height, they are referred to as 'trees'.

The estate fields vary in age and origin of the seed used in planting them. It is necessary to specify the progenies of three distinct importations of seed which are represented at Kapretwa Estate as 'French Mission', 'Mysore', and 'Blue Mountain'. The 'French Mission' coffee was planted in 1925, 1926, and 1927 from seed which came from the St. Austin's Mission near Nairobi. This estate was planted from the progeny of seed originally introduced from Aden in 1893. There were

6 plots in a field of 'French Mission' coffee at Kapretwa, 5 of these consisting of 16 trees and 1 plot containing 36 trees. The 'Mysore' coffee was planted in 1928 from seed produced at an estate where coffee had been introduced from India; there was one plot at Kapretwa containing 1,155 trees. The 'Blue Mountain' coffee was planted in 1930 and 1931 from seed produced in Jamaica; there were 2 plots each containing 25 trees in a field at Kapretwa.

Methods

1. *Selection of plots.*—The yields of coffee trees were recorded individually in the 9 plots referred to above, which ranged in size from $\frac{1}{12}$th acre to approximately 2 acres. It was not practicable to record yields over a wide area on the estate, because the reliability and accuracy of the results would have suffered through difficulties in supervising the work with the limited staff available. Within their allotted fields the plots were chosen at random, except that they were selected so that there were no vacant plant-sites within the confines of the plots representing 'French Mission' and the 'Blue Mountain' coffee. The plot area in the 'Mysore' coffee field should have contained 1,200 trees, but only 1,155 of these were present.

2. *Crop-recording.*—The ripe coffee from each tree was picked and the weight observed on a spring-scale read to the nearest $\frac{1}{4}$ oz. The accuracy of this scale was periodically checked with weights. The writer believes that sufficient precision was obtained with the spring-scale, considering the variability of the material. This variability arises through differences in moisture-content due to abnormal ripening and to diurnal changes in humidity.

The berry normally changes from green to red as it ripens; a full development of the red colour indicates the stage at which it is desirable to pick. However, all berries do not ripen normally or evenly, some pass from green to a yellow-ripe stage without turning red. Such abnormal ripening is evidently associated with the water and nutrient status of the tree; consequently the proportion of pulp in the fresh coffee varies according to the nature of the ripening process. Fresh coffee is hygroscopic, as shown by Thomas [3], and may vary greatly in moisture-content because the succulent pulp comprises about half the total weight of the berry. It is evident that yields recorded on fresh weights will not be as reliable as those in terms of the final dry product. Nevertheless, it is sufficient for most purposes that yields should be determined on fresh weights, provided that the limitations of such data are appreciated.

The picking of individual trees began at the same time as the first estate picking, which normally starts when there is sufficient ripe coffee present to be economically worth harvesting. It usually happens that before this date some very early trees are bearing some ripe coffee. At the end of the season there are a few trees still carrying ripe or immature coffee. The estate practice is to remove all the coffee remaining on these 'late' trees, including both over-ripe and unripe berries, when the majority of the trees have been completely picked. This final harvesting is referred to as 'stripping'; such coffee is not pulped but merely dried, to

give the product known as *mbuni*. In view of the relatively low economic value of *mbuni* at the time of this investigation, the 'strippings' were ignored in recording the yields of the 'French Mission' and 'Blue Mountain' coffee, but they were considered in the case of the 'Mysore' coffee. The picking-rounds are usually at intervals of a week or longer. The weights of cherry coffee are totals of several 'pickings' of which there might be as many as nine.

3. *Preparation out-turns.*—The words 'berry' and 'cherry' are generally used somewhat loosely in referring to fresh coffee. It is considered preferable to use the word *berry* only when referring to the crop on the trees, whilst *cherry* will be the term applied to the ripe coffee when picked from the trees and before it receives any factory preparation. In order to obtain the data on out-turns (which are considered in Part II) the individual lots of cherry coffee were pulped in a hand-machine. In this way either small or large 'pickings' from the individual trees could be handled conveniently. The preparation of the coffee was completed in the laboratory and included the following stages: (1) under-water fermentation, (2) hand-washing, (3) sun-drying, and (4) hand-hulling.

Results

1. *Comparison of estate and plot yields.*—A count was made of all the coffee trees on Kapretwa Estate. This census was undertaken because there was no certainty that the known acreage of the coffee was a reliable guide to the number of the individuals contributing to the total yield of the plantation. It is useful for present purposes to know the average yield per tree for the whole estate, because a comparison is then possible with the individual tree yields obtained in this investigation. The estate yields are only available in terms of 'clean coffee', which is the final product, because it was not the local practice to weigh the fresh coffee. In order to compare the yields from the whole estate with those determined in the recorded plots, it has been necessary to convert the latter from weights of fresh coffee to their equivalent in terms of 'clean coffee'. An arbitrary figure of 6·2 has been taken as the conversion factor, this figure representing the number of pounds of fresh coffee required to give one pound of 'clean coffee'. In Table 2 the estate yields are compared with those from the recorded plots.

TABLE 2. *Coffee Yields at Kapretwa Estate* (*pounds of 'clean coffee' per tree*)

	Whole estate, area 140 acres	*Plots*		
		French Mission ($\frac{1}{6}$ *acre*)	*Blue Mountain* ($\frac{1}{12}$ *acre*)	*Mysore* (*2 acres*)
1934–5 . .	0·7	0·7	..	..
1935–6 . .	1·3	3·1	0·9	..
1936–7 . .	0·4	0·9	0·5	..
1937–8 . .	1·2	3·1	1·7	6·4
1938–9 . .	0·6	0·8	0·3	1·4
Mean . .	0·84	1·72	0·85	3·90

This table shows that results for individual trees, determined with some accuracy in the course of plot-recording, are in general accordance with the yields from the whole estate in terms of total coffee produced and total number of trees picked.

2. *Overcropping.*—During this study of individual tree yields it was noticed that where the trees were carrying very large crops the berries often failed to mature properly, presumably owing to shortage of water, or of nutrients, or both. Thus it happens that, on the average, the larger the crop the greater is the amount of 'strippings', as shown by the positive and significant correlation coefficients in Table 3.

TABLE 3. *Mean Yields of 1,155 'Mysore' Trees (pounds of cherry and strippings)*

	1937–8	*1938–9*
Cherry (*X*), mean per tree . . .	8·5	39·7
Coefficient of variation . . .	82·1%	48·0%
'Strippings' (*Y*), mean per tree . .	0·9	1·4
Correlation coefficient, *rxy* . . .	+0·213*	+0·458*

* Both correlation coefficients are highly significant, $P<0.001$.

The inference to be drawn from the positive correlation is that a very large crop on a tree may not be economic, because much of it is likely to be of a low value through being 'stripped' for *mbuni*. The ideal would seem to be that a tree should carry only such an amount of coffee as it can mature properly within the picking season. Another unfortunate result of overcropping is the biennial-bearing with which it is typically associated; this feature of seasonal cropping will be discussed later.

3. *Variability of individual tree yields.*—In Arabica coffee, as with other plantation crops, there is known to be a wide range of individual tree yields. This variability is indicated by the magnitudes of the coefficients of variation in Table 3; and it will be noticed that there appears to be an inverse proportionality between mean yield and coefficient of variation. This general relationship has been found to occur where extensive series of yield data [4, 5, 6] have been examined in this connexion. On that account it would seem that for the purposes of field experiments it might generally be desirable to undertake crop-recording when mean yields are not likely to be very small, or to combine the yields of two or more seasons, as will be explained later.

When the yields of large populations are grouped into classes, then the frequency-distribution approaches symmetry only when the mean is large. The distribution is highly asymmetric when the yields are small, mainly on account of the large proportion of individuals in the '0' class. When the general level of yields is unusually high, there may nevertheless be a disproportionately large number in the lowest yield-class, as shown in Table 4.

TABLE 4. *Frequency Classes of Yields from 1,155 'Mysore' Trees in Two Seasons*

Yield-classes (lb. cherry per tree)	*Frequency (no. of trees)*	
	1937–8	*1938–9*
0–9	727	123
10–19	346	53
20–9	74	136
30–9	8	237
40–9	..	262
50–9	..	176
60–9	..	119
70–9	..	37
80–9	..	10
90–9	..	2
	1,155	1,155
Mean yield (lb.)	8·5	39·7

This table shows, in another form, why it may be undesirable to use the records of one season alone for a field trial, because there may be a large proportion of the experimental trees that will not contribute appreciable yields.

4. *Varietal yield differences.*—In recording the 2-acre block of 'Mysore' coffee the opportunity was taken to classify 1,134 trees on leaf-shape (wide or narrow) and on tip-colour (green or bronze), as shown in Table 5.

TABLE 5. *Mean Yields (pounds of cherry per tree) for 1,134 'Mysore' Trees, classified on Leaf-shape (wide or narrow) and on Tip-colour (green or bronze)*

	Leaf-shape					
	Wide		*Narrow*			
Tip-colour	*Number*	*Yield*	*Number*	*Yield*	*Total*	
Bronze	740	24·86	45	19·78	785	24·57
Green	343	23·25	6	23·83	349	23·26
Total	1,083	24·35	51	20·26	1,134	24·17

The analysis of variance of the mean yields, summarized in Table 5, confirms the belief that the type with narrow leaves is an undesirable one, yielding in this case significantly ($P<0.05$) less (difference of 4·09 lb.) than the wide-leaf type. The mean yield for bronze-tip (24·57 lb.) is greater than the mean yield for green-tip (23·26 lb.), but the difference (1·31 lb.) in this case is not statistically significant.

5. *Seasonal variation in yield.*—It has been found that when the successive annual crops of a number of trees are analysed by far the greater part of the total variance is that attributable to seasonal variation in yields. The magnitude of such fluctuations from year to year is shown

in Table 2, where it will be noticed that there is a general tendency for high and low yields to alternate, which will be referred to later as the 'on' and 'off' seasons, respectively. These yield fluctuations are of such great importance for estate economics and also in connexion with field experiments that the subject has been given considerable attention in these investigations.

6. *Biennial bearing.*—It has been frequently observed that although two trees may give similar aggregate yields over a period of years, the one may bear regularly whilst the crops of the other will fluctuate greatly. It is therefore useful to have a method for indicating the degree of irregularity and of expressing it quantitatively. Suitable arithmetical methods have been suggested by Hoblyn and others [7]. The procedure proposed for measuring the violence of biennial fluctuations is to divide the difference between two consecutive years by their sum, giving the quantity *I*, which measures the 'intensity of biennial-bearing' and may vary from 0 to 1. A nil value is obtained when the yields are equal, and unity when there is no crop in the 'off' year.

It has been pointed out [7] that *I* tends to be exaggerated when the start is not made in a year when there is a heavy crop. Records are available for 116 'French Mission' trees in 5 seasons (1934–9 inclusive). Although, for the majority of these trees, the first season was an 'off' one, its effect on the *I* values does not appear to have been very marked, as shown in Table 6.

TABLE 6

	Mean yield (lb. cherry) per tree per season		*Mean 'I' per tree*	
	Including 1934–5	*Omitting 1934–5*	*Including 1934–5*	*Omitting 1934–5*
Aggregate of 116 trees . .	10·68	12·28	0·648	0·647
Individual tree II . . .	13·00	12·43	0·075	0·097
Individual tree III . . .	13·36	14·58	0·298	0·233
Individual tree IV . . .	13·82	16·73	0·490	0·380

The above figures show that the procedure of determining *I* values may be usefully applied in the selection of desirable 'high-yielding' trees, because it provides a quantitative measure of consistency in cropping. This desideratum might be interpreted as 'yielding-ability', in opposition to high yields through periodical 'freak' crops that may not be desirable. On this basis tree II in Table 6 might be preferable to tree IV because it bears more regularly, as indicated by its smaller *I* value. It is noteworthy that trees II, III, and IV were similar in type, being green-tipped with wide leaves. It appeared that other trees of this type in 'French Mission' coffee were also potentially high yielding.

It will be noted (Table 6) that tree II differs from the plot-mean (116 trees), and from trees III and IV, in having a higher *I* value when the 1934–5 yield is omitted. This divergence is due to tree II differing from the majority, for which 1934–5 was an 'off' season. It is therefore evident that any advantage to be gained from an expected lower *I* value when the start is made in a year of high yields, will depend on whether

the trees are 'in step' as regards annual fluctuations. In the case of the 116 trees now being considered, over 90 per cent. were in conformity for their yield-divergence in two seasons, as shown in Table 7.

TABLE 7

March of yields	*Number of trees 'in step'*	*Per cent. of total*
1934–5 < 1935–6 . . .	110	94·8
1934–5 > 1935–6 . . .	6	5·2
	116	100·0

It is not known to what extent such conformity occurs, but the following table shows that for the two seasons 1937–8 and 1938–9 there was pronounced biennial bearing in plots representing two fields (I and II) at Kapretwa and in a recorded field (III) on a neighbouring estate (Teldet).

TABLE 8

Mean yield (lb. cherry) per tree per season				
	1937–8	*1938–9*	*No. of trees*	*Correlation coefficient for 1937–8 and 1938–9 yields*
Field I . .	39·7	8·4	1,155	−0·091*
Field II . .	10·3	2·1	50	−0·471*
Field III . .	8·1	13·4	348	−0·330*

* Highly significant, $P<0.01$.

It will be shown later that such information regarding annual yield-fluctuations may be utilized for crop-recording in field experiments.

7. *Effect of shade on yields.*—There has been insufficient time to study adequately the effect of shade on coffee yields. It would have been desirable to have observed the effects of both natural and artificial shade on coffee after sufficient preliminary data on unshaded coffee had been obtained. In the circumstances, it was only possible to attempt such a comparison for artificial shade, whilst data were obtained on 2 lots of 5 'French Mission' coffee plants, established under the canopies of *Entada abyssinica* trees [1]. The results obtained are, nevertheless, presented (Tables 9 and 10) in the hope that they will evoke further study along similar lines.

TABLE 9. *Mean Yields (lb. cherry) per Tree per Season and Mean Values of 'I' for Four Seasons (1935–9)*

	Number of trees	*Yield*	*I*
No shade . . .	36	12·05 ± 0·720	0·519 ± 0·0386
Artificial shade . .	80	12·39 ± 0·466	0·704 ± 0·0196
Natural shade . . .	10	7·35 ± 0·986	0·442 ± 0·0388

TABLE 10. *Comparison of Yields and 'I' Values for Shaded and Unshaded Trees*

	Differences	
	Yield	*I*
No shade *v.* artificial shade . .	−0·34	−0·185*
No shade *v.* natural shade . .	+4·70*	+0·077
Artificial shade *v.* natural shade .	+5·04*	+0·262*

* Highly significant, $P<0{\cdot}01$.

The mean yield for 'natural shade' is significantly less than that for either 'artificial shade' or for 'no shade'. This result is not entirely unexpected, because it is known that too much shade may depress yields [1]. However, it will be shown in Part II that the quality of shaded coffee may be better than that of coffee grown without shade.

It is generally supposed that shading reduces the violence of annual yield-fluctuation; therefore it was somewhat surprising to find that the *I* value for 'artificial shade' was significantly greater than that for 'no shade'. This unexpected result is apparently explained by the following observations. The immediate effect of the artificial shade was to increase the leafage of the tall stems and also to promote extension-growth, which was to some extent hampered on reaching the canopy above. Meantime the next cycle in the multiple-stem system, consisting of young suckers, was developing in rather dense shade. These suckers, destined to succeed the old stems, were now shaded by the artificial canopy together with the extra leafage of the tall stems referred to above. When the old stems were cut in the normal course of the pruning cycle, the suckers below were found to be 'drawn', compared with those of the corresponding trees that were not receiving artificial shade; consequently, the second-cycle stems of the shaded trees were weak and unable to carry good crops because they had been previously over-shaded. It appeared that it was in this way that cropping was adversely affected in the trees that were suddenly provided with a shade canopy, and biennial-bearing intensity was thereby increased. This would not necessarily happen where shade conditions had existed for longer, or during the entire life of the coffee, as with trees under natural shade (Tables 9 and 10), where *I* is less than that for 'no shade', but not significantly so. It is possible that this difference might be significant if data were available for a larger number of shaded trees.

8. *Application of combined yields in field experiments.*—It has been shown above that the occurrence of the biennial-bearing 'habit' in Arabica coffee indicates the desirability of using a combination of two or more consecutive seasons' yields in order to reduce the variabilities 'between trees' and 'between seasons', especially the latter, because it is likely to be the larger contributor to the total variance. The reduction in the coefficient of variation through combined yields is illustrated in Table 11.

TABLE 11. *Mean Yields (lb. cherry) per Tree per Season, and Coefficients of Variation for 116 'French Mission' Trees in the Period 1934–9*

	Yield	*Coefficient of variation (per cent.)*
5 seasons 1934–9 . .	10·68	34·6
4 „ 1935–9 . .	12·28	34·6
3 „ 1936–9 . .	9·90	35·0
2 „ 1937–9 . .	12·12	39·7
1 season 1938–9 . .	4·90	73·9

It is evident that a considerable reduction in the coefficient of variation results when three or more seasons' yields are combined. It is not known what improvement there might be if a longer series of annual records were available. It seems unlikely that the gain in precision would be commensurate with the delay involved in obtaining the results.

The coefficient of variation has another useful application along the lines indicated by Paterson [8]. On the assumption that such coefficients from previous years' data are representative, they may be used to evaluate certain statistics which can be of material assistance in the planning of further experiments. A figure may be obtained for the number of replicates of each treatment that would be required to demonstrate real treatment-differences when such differences are greater than a given percentage of the treatment-mean.

The application of this statistical technique is shown for 80 'French Mission' trees, representing 5 plots each of 16 trees, recorded in the period 1934–9 (Tables 12 and 13).

TABLE 12. *Mean Yield (lb. cherry) per Tree and Coefficient of Variation as per cent. of the Mean; with Numbers of Replicates required to detect Differences exceeding 10 and 20 per cent. of the Mean*

	Mean yield	*Coefficient of variation (per cent.)*	*Number of replicates required*	
			10%	*20%*
1934–5	4·06	29·0	68	17
1935–6	18·82	12·8	14	6
1936–7	4·60	71·6	411	103
1937–8	21·42	17·2	25	8
1938–9	4·46	30·2	73	20

TABLE 13. *Data of Table 12 used to give Combined Yields*

	Mean yield	*Coefficient of variation (per cent.)*	*Number of replicates required*	
			10%	*20%*
5 seasons 1934–9 . .	10·70	9·3	8	4
4 „ 1935–9 . .	12·40	8·6	8	4
3 „ 1936–9 . .	10·16	7·7	7	3
2 „ 1937–9 . .	12·94	16·2	21	7

The Tables show that except in 'on' seasons an inconveniently large number of replicates would be required to detect 20 per cent. differences from a single season's crop records. It would appear from Table 13 that at least 4 and possibly as many as 7 replicates of each treatment will be necessary, using the combined yields of at least 2 seasons, in order to detect a 20 per cent. treatment-difference. It is probably quite fortuitous that yields of three seasons combined (Table 13) gave the smallest coefficient of variation.

The consideration of natural yields of coffee on one estate shows the limitations of such material for experimental purposes. Gilbert [9] found for an estate in Tanganyika Territory that 20 trees per plot was a suitable size, and noted that differences of 33 per cent. could be demonstrated, using either 2 or 3 years' natural yields, according to the age and evenness of the blocks. This is in general accordance with the present findings, based on plots of 16 trees to show the order of replications required for one season and for combined yields so as to detect differences exceeding 10 and 20 per cent. of the mean. It may be noted that when the coefficient of variation lies between 12 and 16 per cent., the numbers of replicates required to detect a 20 per cent. difference are within the range of 5 to 7. In order to detect differences at the 33 per cent. level, 3 replicates would be required when the coefficient of variation is 12 per cent. and 4 when the coefficient is 16 per cent. of the mean.

Summary

1. A description is given of the natural yields of Arabica coffee, which were studied during an investigation of a disease-problem.

2. The climate, soil, and nature of the plantation where the study was undertaken are described.

3. Individual tree yields are used to demonstrate the degree of variability, which is greater when crops in general are small.

4. 'Mysore' coffee trees with wide leaves gave higher yields than trees with narrow leaves. The difference in favour of bronze-tip, as opposed to green-tip, trees was not significant for 'Mysore' trees.

5. Biennial bearing is very prevalent and its intensity is expressed quantitatively as *I* values.

6. The crop data are used to make suggestions in regard to plot experiments. It is highly desirable to combine 2 or more seasons' yields.

7. About 20 trees per plot appear to be a suitable size, and 7 replicates of each treatment may be expected to demonstrate differences of the order of 20 per cent. when 2 or more seasons' combined yields are used.

Acknowledgements.—The writer is indebted to Major T. H. E. Jackson for generous provision of facilities, including unlimited scope for observations and experiments in the plantation. Thanks are due to Mr. H. B. Swann and Mr. J. Perkins, owners of Teldet Estates, for permission to use their individual tree records and for assistance in various ways. The writer is indebted to Mr. J. C. Muir, Director of Agriculture, for advice

in the preparation of this paper. Grateful acknowledgement is made for suggestions regarding statistical treatment of the data received from Mr. D. D. Paterson, formerly Professor of Agriculture at the Imperial College of Tropical Agriculture.

REFERENCES

1. C. A. THOROLD, Elgon Dieback Disease of Coffee. E. Afr. Agric. J., 1945, **22,** 203–6.
2. A. WALTER, The Climate of the Coffee Areas of Kenya, 'Coffee in Kenya', Government Printer, Nairobi, 1937.
3. A. S. THOMAS, Some Observations on the Hygroscopic Properties of Dried Coffee Beans and Berries. E. Afr. Agric. J., 1937, **3,** 147–52.
4. S. M. GILBERT, Individual Tree Records of *Coffea arabica*. Coffee Board of Kenya, 1935, Monthly Bull. No. 1.
5. —— Variability in Yield of *Coffea arabica*. E. Afr. Agric. J., 1938, **4,** 131–9.
6. M. HALCROW, Individual Tree Recording for Yield and Quality. Coffee Board of Kenya, 1939, Monthly Bull. No. 3.
7. T. N. HOBLYN, N. H. GRUB, A. C. PAINTER, and B. L. WATES, Studies in Biennial Bearing, I. J. Pomology and Hort. Sci., 1936, **14,** 39–76.
8. D. D. PATERSON, 'Statistical Technique in Agricultural Research', p. 65 and Appendix Table VII, McGraw-Hill, 1939.
9. S. M. GILBERT, Plot-size in Field Experiments with *Coffea arabica*. Trop. Agric., 1938, **15,** 52–5.

(*Received November 12, 1946*)

THE CONSTRUCTION OF CONFOUNDING ARRANGEMENTS

D. J. FINNEY

(*Lecturer in the Design and Analysis of Scientific Experiment, University of Oxford*)

1. *Introduction.*—The device of confounding for the reduction of block-size was originally developed for use in field experiments, but is probably now familiar to all who use experiments of factorial design. The statistical analysis of confounded designs has no special difficulties, but the experimenter often encounters difficulty at an earlier stage, namely, in the subdivision of the treatment-combinations into blocks so as to confound specified contrasts. Yates [1] has listed a number of confounding arrangements and has suggested suitable sets of contrasts for confounding in other cases, but the systematic method of construction of these arrangements, though familiar to statisticians, does not seem to have been published. This paper describes a general method, applicable to any experiment in which all factors are tested at the same number of levels, and is intended to be understood by all who have experience of factorial experimentation. No explanation of the rules will be given, but the reader who applies them to the construction of simple arrangements with which he is familiar should thereby satisfy himself of their generality.

2. *Factors at two levels.*—In the simplest type of factorial experiment, that for which every factor has two alternative levels (a 2^n design), any treatment-combination is denoted by a symbol consisting of small letters for all factors at the upper level, no letters for those at the lower. For example, the symbol *bce* represents the combination of the upper levels of the factors B, C, and E with the lower levels of the factors A, D, and any others in the experiment. Often a factor is the contrast between 'treated' (upper level) and 'untreated' (lower level), as, for example, 'with' and 'without' nitrogenous fertilizer. When there is no true 'upper' or 'lower', as in a contrast between two methods of cultivation, one state is arbitrarily chosen as upper and the letter used to indicate that. For reasons which will be apparent later, the symbol (1), rather than zero, is used to represent the combination of the lower levels of every factor. The main effects and interactions of the factors, the treatment-contrasts, are represented by the corresponding capital letters, so that, for example, the symbol BCE represents the interaction of the three factors B, C, and E.

An experiment with n factors involves 2^n treatment-combinations. The simplest confounding scheme is that requiring the division of these into two blocks of 2^{n-1} so as to confound one of the 2^{n-1} contrasts corresponding to main effects and interactions. For example, if there are four factors and the interaction ABC is to be confounded, one block will contain all treatment-combinations whose symbols have an even number of the letters *a*, *b*, *c*, irrespective of other letters. Since zero is an even number, the first such symbols are (1), *d*, and the others *ab*, *abd*, *ac*, *acd*, *bc*, *bcd*; the remaining eight combinations form the second

block. The block containing the combination (1) will be termed the *principal block*.

If blocks of size 2^{n-2} are required, three degrees of freedom must be confounded. Two of the contrasts for confounding can be chosen arbitrarily, but the third is then determined as the *product* of the symbols for the first two. These are not ordinary algebraic symbols, however, and their product is not an ordinary algebraic product. If *AB* and *CD* are confounded, then the product which is necessarily confounded is *ABCD*, but if *ABC* and *ACD* are confounded, the product is *BD* and not A^2BC^2D: the rule is to form the product according to the rules of ordinary algebra, but afterwards to replace the square of any letter by unity. The reason for using the word 'product' will be clearer after the discussion of factors at three levels, and for the present the rule may be considered as merely an aid to the memory in forming the third contrast from the first two. The product of *any* two of the confounded contrasts is the third, as may easily be verified (the product of *ACD* and *BD* is *ABC*, since D^2 is unity).

The principal block of the design consists of those combinations whose symbols contain an even number of letters from each of the confounded contrasts. For four factors, with *ABC*, *ACD*, *BD* confounded, this block is made up of the four combinations (1) (no letters from any of the contrasts), *ac* (two from the first and second, none from the third), *abd* (two from each), *bcd* (two from each). After a little practice, such combinations can be found quite rapidly, either by trial and error or, a little more systematically, by specifying one or two letters and finding what conditions must be satisfied by the remainder of the combination. The product of any two symbols in the principal block also belongs to that block, a property which assists the construction of the block. Thus when *ac* and *abd* have been found, their product, *bcd*, is determined; the symbol (1) is interpreted as unity, so that its product with *ac* is *ac*. The remaining three blocks can now easily be derived by a further use of the product rule. If every member of the principal block is multiplied in turn by any one treatment-combination not included in the block, a second block is generated. The process can be repeated with another combination that has not already occurred, and again a third time, as below:

Block I	(*Multiply by* a) *Block II*	(*Multiply by* bc) *Block III*	(*Multiply by* ad) *Block IV*
(1)	*a*	*bc*	*ad*
ac	*c*	*ab*	*cd*
abd	*bd*	*acd*	*b*
bcd	*abcd*	*d*	*abc*

Here blocks II, III, IV have been obtained from block I by multiplication of its members by *a*, *bc*, *ad* respectively. All the sixteen combinations have then been exhausted, and if any further multiplication is tried one block is generated again in a different order; for example, if *ab* is used as a multiplier, block III is obtained again, or if *abd* is used, block I is obtained.

Designs for larger values of n and for larger sets of confounded interactions can be developed in the same manner. The general application of these rules should be clear from the following example of the confounding of six factors at two levels into eight blocks of eight. The first step is to select the seven contrasts for confounding, a choice which can be made only after careful consideration of the objects of the particular experiment; usually the high-order interactions can best be spared, but occasionally even main effects may be chosen. If main effects and two-factor interactions are to be unconfounded, it will be found that *ABCDEF* and the six five-factor interactions must also be unconfounded. Suppose that *ABCD* and *ABEF* are chosen for confounding; then the product rule shows that *CDEF* must also be confounded. One more contrast must then be chosen, this time necessarily a three-factor interaction; if this is *ACE*, the product rule shows *BDE*, *BCF*, *ADF* also to be confounded. The product of any two of the seven is also one of them.

Next the principal block must be formed. Trial shows that *acf* and *ade* each contain an even number of letters from every one of the confounded contrasts, so that they and their product, *cdef*, belong to the block. Similarly *bdf* belongs, and therefore also do its products with the other three. The complete block is:

(1), *acf*, *ade*, *cdef*, *bdf*, *abcd*, *abef*, *bce*.

A second block is obtained from a multiplication of the first by *a*, and is:

a, *cf*, *de*, *acdef*, *abdf*, *bcd*, *bef*, *abce*;

the other blocks can be formed by multiplication of the first by *b*, *c*, *d*, *e*, *f*, *ab*. Many alternative sets of multipliers could be used, but for simplicity each block is generated from the least complex symbol that has not previously occurred.

3. *Factors at three levels.*—Fisher [2] and Finney [3] have indicated how the notation used for factors at two levels may be extended to experiments with n factors each at three levels. The levels of a factor A are denoted by a^0 or unity for the lowest, a^1 or merely a for the middle, and a^2 for the highest, so that a^2cd^2 . . . represents the combination of the highest level of factor A, the lowest of B, the middle of C, the highest of D, and so on; once again (1) denotes the combination of the lowest levels of all factors.

The main effect of the factor A has two degrees of freedom, and may be denoted by A, A^2—two symbols because of the two degrees of freedom, but the two will always occur together. The interaction of A and B (Yates's $A.B$) has four degrees of freedom, and these are denoted by AB, A^2B^2, A^2B, AB^2. Yates [1, Section 9 *e*) used the notation I and J for two pairs of degrees of freedom from the interaction of two factors; the notation used here is less concise but generalizes more easily to interactions of higher order. Yates defined the I component of the interaction as the contrasts between the totals of (1), ab, a^2b^2; a, a^2b, b^2; a^2, b, ab^2, and the J component as the contrasts between totals of (1), a^2b, ab^2;

a, b, a^2b^2; a^2, ab, b^2. If the first set of either is multiplied by a, with the special condition that after multiplication a^3 is replaced by unity (and therefore a^4 by a), the second is obtained; similarly if the first set is multiplied by a^2 the third is obtained. The condition that in forming products, a^3, b^3, c^3, . . . are to be put equal to unity, replaces the condition, for factors at two levels, that the square of every letter is unity, and again the same rule applies to the capital letters. Furthermore, if the pair of symbols A^2B, AB^2 is taken to correspond with I, and the pair AB, A^2B^2 with $\mathcal{J}$, the sum of products of the powers of the capital letters with the powers of the small letters in any one of the members of the principal block—the block containing (1)—of the arrangement for confounding the contrast represented by the symbols in capitals is divisible by three. This rule, which is a little cumbrous in words, corresponds to the rule of 'even-ness' for factors at two levels. A more general statement is that, if a contrast $A^PB^QC^RD^S\ldots$ is to be confounded and $a^pb^qc^rd^s\ldots$ is any member of the principal block (where P, Q, R, S, . . . and p, q, r, s, . . . can take the values 0, 1, or 2),

$$Pp + Qq + Rr + Ss + \ldots$$

must be divisible by three. The property that the product of the symbols for any two confounded contrasts, including now the square of any one, must also be confounded remains true for the 3^n arrangements. One or two examples should clarify these rather involved statements. Yates has given the block constitutions for these designs, but the explanation that follows may help the understanding of the method of construction and the development of more complex designs if required.

Suppose that an experiment is to contain three factors at three levels, giving twenty-seven combinations of levels, and that it is to be arranged in three blocks of nine. There are eight degrees of freedom for the three-factor interaction, and a pair of these, say AB^2C and its square, A^2BC^2, might be chosen for confounding. The principal block will contain the nine symbols for treatment-combinations of the form $a^pb^qc^r$ for which $p+2q+r$ is divisible by three; that $2p+q+2r$ is then also divisible by three is easily verified. The triads of values may be found by fixing p, q, and determining r. They are 0,0,0; 1,0,2; 2,0,1; 0,1,1; 1,1,0; 2,1,2; 0,2,2; 1,2,1; 2,2,0; hence the principal block is

$$(1),\ ac^2,\ a^2c,\ bc,\ ab,\ a^2bc^2,\ b^2c^2,\ ab^2c,\ a^2b^2,$$

which once again has the property that the product of any two of its members is also a member. Multiplication of the members of the principal block by any symbol not itself a member generates another block of the design. The simplest multipliers which give the other two blocks are a and a^2, whence the second block is

$$a,\ a^2c^2,\ c,\ abc,\ a^2b,\ bc^2,\ ab^2c^2,\ a^2b^2c,\ b^2,$$

and the third

$$a^2,\ c^2,\ ac,\ a^2bc,\ b,\ abc^2,\ a^2b^2c^2,\ b^2c,\ ab^2.$$

Comparison with Yates's Table 43 [1] shows these three blocks to be his X_1, X_2, X_3, so that the component of the three-factor interaction which

he calls X is now denoted by AB^2C, A^2BC^2. In a similar manner may be established the identity of his W with A^2BC, AB^2C^2, his Y with ABC^2, A^2B^2C, and his Z with ABC, $A^2B^2C^2$.*

Consider now an experiment consisting of four factors at three levels. The sixteen degrees of freedom for the four-factor interaction fall into eight pairs, and an arrangement in three blocks of twenty-seven, confounding any one of these pairs, say, AB^2C^2D, A^2BCD^2, can be derived just as for the 3^3 experiment discussed above; for $a^pb^qc^rd^s$ to be a member of the principal block, $p+2q+2r+s$ must be divisible by three. But for many purposes blocks of twenty-seven are too large, and an arrangement in nine blocks of nine is likely to be required. If a pair of contrasts from a three-factor interaction is also chosen for confounding, say, AB^2C, A^2BC^2, then the products of these symbols with the other pair must also be confounded; these are A^2BD, AB^2D^2, CD, C^2D^2. If a second component of the four-factor interaction had been used instead of AB^2C, either a main effect or a two-factor interaction would have been amongst the products. Trial soon shows that, if any component of the four-factor interaction is confounded, amongst the other six degrees of freedom must be either a main effect or a component of a two-factor interaction. There are, however, eight possible arrangements which confound two degrees of freedom from each of the three-factor interactions. If ABC^2 and AB^2D are chosen, their squares, A^2B^2C and A^2BD^2, and all products of these, A^2C^2D, ACD^2, BCD, $B^2C^2D^2$, must also be confounded. The members of the principal block of the design, the fourth of those which Yates gave in his Table 49, must satisfy the conditions that $p+q+2r$ and $p+2q+s$ are divisible by three, and each of the six similar expressions is then necessarily also divisible by three. Once again the block may be obtained by selecting values of p, q and finding r, s; thus when $p = 1$ and $q = 2$, $2r+3$ and $s+5$ must be divisible by three, whence $r = 0$ and $s = 1$. In this way the principal block is found to be

$$(1),\ acd^2,\ a^2c^2d,\ bcd,\ abc^2,\ a^2bd^2,\ b^2c^2d^2,\ ab^2d,\ a^2b^2c,$$

and multiplication by a, a^2, b, b^2, ab, a^2b^2, ab^2, a^2b will then generate the other eight blocks.

4. *Factors at more than three levels.*—The rules for the construction of confounding arrangements will extend to factors at more than three levels, providing that the number of levels is either a prime or a power of a prime. These designs are of lesser utility, and will not be discussed in detail here, but the method presents no new features. For factors at five levels, for example, the levels are denoted by powers of letters from 0 to 4, and the fifth powers instead of the third are put equal to unity; the degrees of freedom for main effects and interactions then fall into groups of four instead of into pairs. In constructing the principal block,

* The notation shows that Z is independent of the order of the factors, but that the other three components are not. The component known as W when the factors are in the order A, B, C, is also W when they are written in the order A, C, B, but becomes Y if they are written in the order C, B, A. When using the arrangements listed by Yates, experimenters must take care that their factors are in the right order for correspondence with Yates's; failure to observe this precaution may lead to the confounding of the wrong contrasts and confusion in the statistical analysis.

a condition of divisibility by five replaces that of divisibility by three. When the number of levels is a power of a prime, each factor may be formally regarded as several pseudo-factors each at a prime number of levels [1, Section 14]. For example, a confounding scheme for factors at four levels may be found by treating each factor as though it were the four combinations of two two-level factors; the design should then be rewritten in terms of the true factors and examined carefully before use, in order to ensure that no important contrast is inadvertently confounded.

Designs in which the factors do not all have the same number of levels cannot be formed by direct application of the methods given here. The reader who has mastered the technique described in Sections 3 and 4, however, should have little difficulty in understanding the structure of these more complex partially confounded designs.

5. *Summary.*—The systematic formation of the blocks for the confounding of factorial experiments has been described, with special reference to 2^n and 3^n designs. The method makes clear the relationships between the several confounded contrasts and the restrictions on their free choice, and, once these contrasts have been selected, enables the constitution of the blocks to be determined by the application of a few simple rules.

REFERENCES

1. F. YATES, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci., 1937, Tech. Commun. No. 35.
2. R. A. FISHER, The Theory of Confounding in Factorial Experiments in relation to the Theory of Groups. Ann. Eugen., Lond., 1942, **11**, 41–53.
3. D. J. FINNEY, The Fractional Replication of Factorial Arrangements. Ibid., 1945, **12**, 291–301.

(*Received December 3, 1946*)

LUCERNE GROWING

A. G. DAVIS

(Grassland Improvement Station, Stratford-on-Avon)

LUCERNE, or alfalfa, as it is known in America, has an important part to play in helping to fill the gap in mid summer, particularly for dairy stock, as well as its great value as a hay crop in dry areas. However, a glance through the agricultural returns shows that the acreage was not, up to the war, very large: the maximum of 65,000 in 1924 dropped to 31,802 in 1939, and the bulk of that acreage was in the counties of Essex and Kent. The returns no longer make any provision for lucerne as a separate entity and so we can only surmise what is the present extent of its popularity. In the United States alfalfa has moved eastwards across the continent to leap into the limelight as the saviour of the dairy industry in some of the north-eastern States. The total United States acreage of some 14 million acres has been accompanied by a decrease in the age of the stands, an increase in disease and insect pests, and an extended use of it for grazing purposes. For example, despite our knowledge of the requirements of the crop—well-drained soils, lime, phosphate, potash, and inoculation—there appear to be additional factors which must be elucidated before we can look to a greatly extended acreage of lucerne in England. It is the purpose of this paper to report upon recent studies of companion-plants for lucerne, seed-rate, and method of management.

Companion-plants and seed-rates.—The case for a companion-grass rests on the assumption that a pure stand is much more difficult to make as hay, to handle for grazing, and that it is also more likely to cause bloating than is a stand containing one or more grasses. It is not easy to determine how far this assumption is true except by observation. Also there is the matter of weed-control and studies of yields; plant-population and degree of weediness have clearly shown the need for a mixture and not just a pure sowing of lucerne. Careful analysis of the hay, cut in its third year, from current trials[1] on lias-clay land in Warwickshire, confirm this view. The data obtained are presented in Table 1.

TABLE 1. *Dry-matter Yields (in lb. per acre) of Separated Herbage from Plots Sown with Lucerne only and Lucerne with Cocksfoot and Timothy (Relative Yields in Brackets)*

	Lucerne	*Sown grass*	*Weeds*	*Total herbage*
Yield of lucerne pt.	2,380 (100)	..	3,180 (100)	5,560 (100)
Yield of lucerne with S. 37 cocksfoot and S. 51 timothy	3,380 (142)	2,760	2,090 (65)	8,230 (148)

[1] Development trials conducted by the Grassland Improvement Station.

Where lucerne was sown with S. 37 cocksfoot and S. 51 timothy it yielded 42 per cent. more than where it was sown alone. The weight of weeds in the mixture was only 65 per cent. of that present in the plot sown with lucerne alone. The total weight of herbage from the mixture was 48 per cent. more than that obtained from the pure lucerne sowing.

Counts of lucerne plants with various companion-grasses were made in the third year on a stand sown at the Colesbourne sub-station of the Grassland Improvement Station on a brashy soil in the high Cotswolds. They show the combined effect of seed-rate, companion-plant, and management (Table 2).

TABLE 2. *Number of Lucerne Plants per sq. ft. on July 12, 1945, on a Three-year-old Stand at Southbury Farm, Colesbourne*

Seeds-mixture			*Management*	
No.	*Lucerne (lb. per acre)*	*Companion-plants (lb. per acre)*	*Two hay-cuts in 1944 (plants per sq. ft.)*	*One hay-cut and then close-folding late summer, 1944 (plants per sq. ft.)*
1	10	Perennial ryegrass 3 S. 37 cocksfoot 6 Montgomery red clover 1 New Zealand white clover 1	2	..
2	20	S. 37 cocksfoot 6	15	..
3	20	S. 48 timothy 8	34	15
4	30	S. 37 cocksfoot 6	28	10
5	40	S. 37 cocksfoot 6	37	..

Lucerne at 10 lb. per acre and in the presence of perennial ryegrass, even at so low a seed-rate as 3 lb. per acre, together with cocksfoot, is unable to withstand the competition. In this particular mixture New Zealand certified mother-seed perennial ryegrass was used, which, owing to its earliness relative to ordinary commercial ryegrass, smothered the lucerne before the latter commenced the new season's growth. The S. 37 cocksfoot made a good establishment and grew rapidly aggressive towards the lucerne. Increasing seed-rate of the lucerne in the presence of cocksfoot resulted in an increased plant-population of lucerne, but the heavy seeding of 40 lb. per acre produced only 37 plants per sq. ft., whereas 20 lb. per acre with S. 48 timothy as a companion-grass gave 34 plants per sq. ft. Timothy is relatively non-aggressive, and it is necessary to maintain a balance of each species in the hay. The close folding of the aftermath in the late summer of 1944 reduced the stand of lucerne by more than a half compared with a stand not so folded in 1944. Such treatment was not sufficient to check the aggressiveness of the cocksfoot compared with the timothy, and, again, the lucerne was thinner in the cocksfoot plot despite the heavier seed-rate.

Optimum seed-rates of lucerne are governed by the species and strain of companion-plants sown in the mixture. Of the wide range of species and strains from which to select, we have found in our trials that cocks-

foot, timothy, and meadow fescue offer the greatest promise. The ryegrasses, unless used in very small quantities, start growth so early in the season as to smother the lucerne before it makes any appreciable growth, and, if an attempt is made to control them by grazing, the lucerne suffers proportionately. Cocksfoot makes a good companion-plant under the drier conditions of the eastern counties, although it also has its limitations in terms of strain, seed-rate, and management. Thus, data from the trial already referred to in Table 1 show the competitive effect of strains of cocksfoot upon the yield of lucerne, and this is expressed in Table 3 in terms of relative yields.

TABLE 3. *Yields of Lucerne and Total Herbage of Third-year Hay-cuts from a Trial on Heavy Lias Clay. Yields expressed as Relative Values based on 100 for the Lucerne and 100 for the Total Yield from the Plot Sown with Lucerne only*

	Lucerne	*Total yields including unsown species*
Lucerne sown alone	100	100
Lucerne sown with S. 37 cocksfoot and S. 51 timothy	142	148
Lucerne sown with S. 26 cocksfoot and S. 51 timothy	45	106
Lucerne sown with U.S.A. cocksfoot and S. 51 timothy	47	109

In contrast with the S. 37 cocksfoot, both U.S.A. and S. 26 cocksfoot suppressed the lucerne and failed to add appreciably to the total yield of herbage. In higher rainfall areas, cocksfoot will only too readily smother the lucerne and it is proper for us to inquire whether or not we can keep it in check, particularly while the lucerne is more or less dormant. Thus, in 1945, a lucerne-cocksfoot paddock was subdivided: one half was grazed in late October and again in early March, 1946, while the other half was rested. Counts of lucerne made on August 12, 1946, gave 9·1 plants per sq. ft. on the grazed area and 6·2 plants per sq. ft. on the part which was rested in autumn and winter, showing the value of checking the growth of the cocksfoot and the subsequent benefit to the growth of the lucerne. A low seed-rate of cocksfoot may reduce the intensity of its competition but at the same time it will provide too open a sward with an excessive tufted appearance. Critical inspection of a trial on light Cotswold soil, where S. 23 perennial ryegrass was drilled along with lucerne and S. 37 cocksfoot, has revealed a relatively closed sward of sown species without reducing the stand of either lucerne or cocksfoot. There is a case for drilling the lucerne and broadcasting or cross-drilling the cocksfoot, say, 15–20 lb. lucerne and 3–5 lb. of cocksfoot. With the high prices ruling, as at present, it seems essential to reduce the seed-rate.

Timothy fits in very well with lucerne, even though it is late and does not bulk in the aftermath. The advantage of timothy is that it is non-competitive, although that is a relative factor, as has been seen in trials

put down both in 1945 and 1946. Timothy may not be the ideal plant for the lighter soils under dry conditions, but if the lucerne acreage is to be increased in the midland counties and some of the southern counties, timothy can make a great contribution towards that end. The strain S. 48 timothy, with lucerne, gives a very nice hay and also makes a good grazing mixture, being palatable and containing a high proportion of dry matter. In contrast with a cocksfoot-lucerne mixture in which the tendency is for stock to punish severely the lucerne and neglect the cocksfoot, so increasing the effect of competition from the cocksfoot, timothy is always readily grazed and does not become unduly competitive. In a wet season, such as 1946, timothy in the seeding-year is undoubtedly competitive even at a seed-rate as low as 5 lb. per acre. However, it may be appropriately managed by grazing the field in the late autumn after both lucerne and timothy have ceased growth.

Meadow fescue is another grass which can play an important part as a companion with lucerne. The evidence over the two seasons 1945–6, from trials put down in 1945, strongly suggests that meadow fescue throws up a lot of keep without at the same time having a depressing effect upon the lucerne. In a dry season meadow fescue, with its larger seed, stands a better chance of becoming established than does timothy, whilst in a wet year it does not appear to compete unduly with the lucerne. Thus, it would seem to have a use in lucerne leys over a belt of country mid-way between the dry east and the wet west of Britain. Five lb. of seed per acre is ample and a good take and growth have been obtained in the first season from sowings of pedigree seed. This is illustrated in Table 4 based upon a Station trial, from which hay yields were taken in the autumn of the seeding-year. The S. 215 hay strain of meadow fescue is a very promising companion-plant to lucerne, as it becomes established fairly quickly, prevents the invasion of unsown species, and is leafy. Its ability to grow into the late autumn (and it continues remarkably winter green) is an advantage to the stockman who must graze off the keep in order to check the growth and prevent the grass from getting away too early in the following spring, so suppressing the lucerne.

TABLE 4. *Relative Yields of Meadow Fescue and Lucerne in Three Mixtures with Different Strains of Meadow Fescue*

Meadow fescue	*Relative yield of*	
	Meadow fescue	*Lucerne*
Commercial (U.S.A.) hay type . . .	100	100
S. 53—pasture strain	140	124
S. 215—hay strain	170	118

In America the companion-grass now employed with lucerne is Hungarian brome (*Bromus inermis*). Seed-rates for the two species are 7 lb. of lucerne and 3 lb. of brome per acre. Trials in England, using double the seed-rate, have been disappointing. The brome is very slow in establishing itself and it does not give any appreciable yield.

Annual meadow grass (*Poa annua*) is a weed that causes much concern to the grower of lucerne. *P. annua* tolerates shade, readily seeds itself over a long period of the year, and provides an abundance of viable buried seed, as shown by the work of Milton [1], and more recently at the Grassland Improvement Station [2]. On many soils *P. annua* thrives in the unstable habitat of arable land and particularly in association with lucerne. As with other weeds of arable land, the problem is best tackled by some form of cultivation. Drastic, heavy harrowing after each cutting and continued during the winter should help to control weeds after the lucerne has become fully established. In practice this is not so easy. For instance, if hay is taken and there is some delay in getting it carted off the field, the growth of aftermath is often so rapid as to mitigate the effect of the harrowing; alternatively, the farmer cannot bring himself to put the cultivator into the field for fear of damaging the new growth.

Management.—Various investigators have made the point that too early and too frequent cuttings are likely to kill out the stands. In Table 5 the results are set out in terms of plant-populations of differential treatments on a lucerne-cocksfoot stand in one of the Station trials.

TABLE 5. *The Effect of Differential Management upon the Average Number of Lucerne Plants per sq. ft. in August of the First Harvest Year (1946). Sown with S. 37 Cocksfoot*

Management in 1946	*Lucerne plants per sq. ft.*
Hay cut in June. Aftermath mown Aug. 16	8·5
Hay cut in June. Aftermath grazed by sheep during July	9·0
Grazed monthly by sheep	7·0
Grazed fortnightly by sheep	3·5

From these data it would appear that lucerne will not stand up to repeated close defoliation, especially by sheep. A relatively long interval between grazings is, in practice, beneficial, as the plant can throw up some stem which is not so readily eaten and so protects the crown; the presence of some stemmy fibrous herbage decreases the danger of bloat in cattle and sheep.

'*Strain.*'—A brief reference to the problem of strain or variety in lucerne is necessary. Strain appears to be equally important in lucerne as in other farm crops. In the past the failure of the lucerne crop to extend its acreage must, in part, be due to the absence of knowledge regarding the precise source of seed supplies. The Americans have taken up the certification of lucerne seed with good results. In our trials, seed from the Argentine has given indifferent crops; 'Marlborough' (New Zealand) shows much promise: Grimm and Ontario Variegated are decidedly valuable strains.

The Grassland Improvement Station has some 60 lots of seed of different origin, chiefly from overseas sources, under critical test. These are being subjected to different treatments, including hay and grazing, as well as contrasting levels of manuring.

Acknowledgements.—The writer desires to thank Dr. William Davies for the opportunity of conducting the trials; Mr. T. E. Williams, B.Sc., and Mr. R. Garrett-Jones, B.Sc., for collection of part of the data.

REFERENCES

1. W. E. J. Milton, The Buried Viable Seed-content of a Midland Calcareous Clay Soil. Empire J. Expt. Agric., 1943, **11**, 43–4.
2. Grassland Improvement Station. Unpublished data.

(*Received December 20, 1946*)

THE AGE-DISTRIBUTION OF PEDIGREE CATTLE AND FACTORS AFFECTING IT

H. P. DONALD AND A. A. EL ITRIBY
(*Institute of Animal Genetics, University of Edinburgh*)

IT has been shown by several investigators that in some parts of Britain the average length of productive life of a dairy cow in one herd is about 3·5 years [e.g. 1, 2, 3]. Wastage rates reported by other workers [4, 5] imply the same comparatively short herd-life. Taken in conjunction with estimated losses from various forms of disease, these observations focus attention on very real economic and health problems in spite of the difficulty of taking account of movements between herds and so arriving at total productive life. The age-distributions of cattle are, however, also of interest to those concerned with selective breeding since they determine the interval between generations, thus influencing the annual rate of progress, and govern the potential amount of information available about the sires and dams of young stock. From this point of view most published studies of ages leave something to be desired. For the most part they deal with commercial cattle, which probably contribute but little in the long run to future genotypes and are difficult to trace from herd to herd. Further, as Pettit [3] has pointed out, the average ages given are not necessarily good indications of average length of life, as has sometimes been supposed. Pedigree cattle as the main source of sires are of most interest from the breeding aspect. Some breeds have been studied by Buchanan Smith and Robison [6], who unfortunately do not give the distributions of ages. The average ages reported might arise from various forms of distribution. They are based on the ages of parents of a random sample of registered calves and, although it is not stated, they probably include the appropriate number of animals that have changed owners. This method should give an estimate of herd-life regardless of changes of ownership, provided of course the sample is representative of the actual cow population. Productive life continued in non-pedigree herds is of no great interest in the present connexion.

It might have been expected that with the assumed better conditions in pedigree herds, such estimates of total productive life would be higher than those from commercial herds, but Buchanan Smith and Robison conclude that they are about the same. It is, however, not necessary to infer that productive life in pedigree herds is low only as a result of serious disease losses. When conditions are favourable, populations of pedigree cattle can expand at rates of 15 per cent. or more [7], and this appears to be achieved mainly by retaining animals which would be culled under less favourable conditions. Up to a point productive life must be short because breeders choose to make it so. It has therefore seemed worth while to reconsider some age-distributions in relation to the requirements of performance breeding.

The data used for the purpose have been obtained from the herd-books of the Red Poll, Ayrshire, and Jersey breeds. The whole of the Red Poll pedigree population as at December 1939 has been obtained from herd-lists, but only samples of the parents of registered Ayrshire and Jersey heifers have been used. In addition to ages, details of attestation, milk-recording, and herds where the parents were bred have been recorded wherever possible.

Age-composition of the pedigree Red Poll female population.—At the end of 1939, the herd-lists contained the names and herd-book numbers of 11,534 females in 276 herds. Their ages were deduced from the herd-book numbers to save the labour of looking up the actual dates of birth. This is felt to be justified since the great majority of heifer calves appear in the volume succeeding their year of birth. Neglect of the few that were registered a year or more late entails a slight under-estimate of age which is probably offset by the small error involved in assuming that the average age of animals between x and $x+1$ years was $x+\frac{1}{2}$ years.

Age-distributions obtained in this way are shown in Table 1, for all females as well as for home-bred and non-home-bred females separately. The oldest female was a non-home-bred cow some 21 years of age and there were 47 aged 15 or more years. The average age of all Red Poll

TABLE 1. *Age-distribution of Pedigree Red Poll Females*

Age (years)	*Number*		*Non-home-bred as per cent. of all* ♀♀	*Cum. per cent. all* ♀♀	* *Proportion not surviving*
	Home-bred	*Non-home-bred*			
0–1	2,004	35	1·7	100·0	0·05
1–2	1,821	102	5·3	82·3	0·13
2–3	1,500	164	9·9	65·6	0·15
3–4	1,194	215	15·3	51·2	0·22
4–5	876	221	20·1	39·0	0·22
5–6	675	185	21·5	29·5	0·14
6–7	506	230	31·2	22·0	0·26
7–8	376	167	30·8	15·7	0·33
8–9	270	96	26·2	10·9	0·27
9–10	193	74	27·7	7·8	0·19
10–15	392	191	32·8	5·5	..
15–21	28	19	40·4	0·4	..
Total	9,835	1,699	14·7	..	..

* Proportion of animals of each age which fail to reach the next age.

females (including calves) obtained from these data is 3·9 years, but home-bred animals alone average only 3·1 years. The difference is due to the large numbers of purchased animals found in many herds. These have a comparatively high average age and account for an increasing proportion of the older age-groups. Change of ownership probably improves a cow's expectation of life, not so much because the change may correct nutritional deficiencies, but because it is likely that she will find herself in a herd where the standards of performance are not so high.

Nevertheless, the two chief causes of the difference are assumed to be: (*a*) the tendency to buy and sell stock only after they are a year or more old (so that young stock fall mainly into the home-bred class); and (*b*) the numerous new herds composed largely of purchased animals which are necessarily older than those which are home-bred. This will apply in some degree to the majority of herds.

Since neither the actual numbers of animals reaching exact ages, nor the rate of mortality at various ages are known, only an approximate calculation can be made of the expectation of life. Assuming (from extrapolation) that the 2,039 calves aged 0–1 year are the survivors of 2,100 born, the complete expectation of life at birth of the latter will be about 5·5 years. This applies, of course, only to those calves which it was intended to register. For home-bred cattle the estimate becomes 4·7 years—the time they can expect to remain in the herd in which they were born. Both these values are appreciably larger than the corresponding average ages, as would be expected, since the 'mortality' from one age-group to the next is comparatively low for the youngest age-groups. The difference will not be so great if animals 3 years old or over are considered. Their average age was 6·2 years, or 3·2 years beyond the selected origin, whilst the expectation of life at 3 years of age on the same data would be 3·8 years. The difference is still sufficient, however, to indicate the danger of estimating productive life by the simple process of taking the average age and deducting an arbitrary age at first calving.

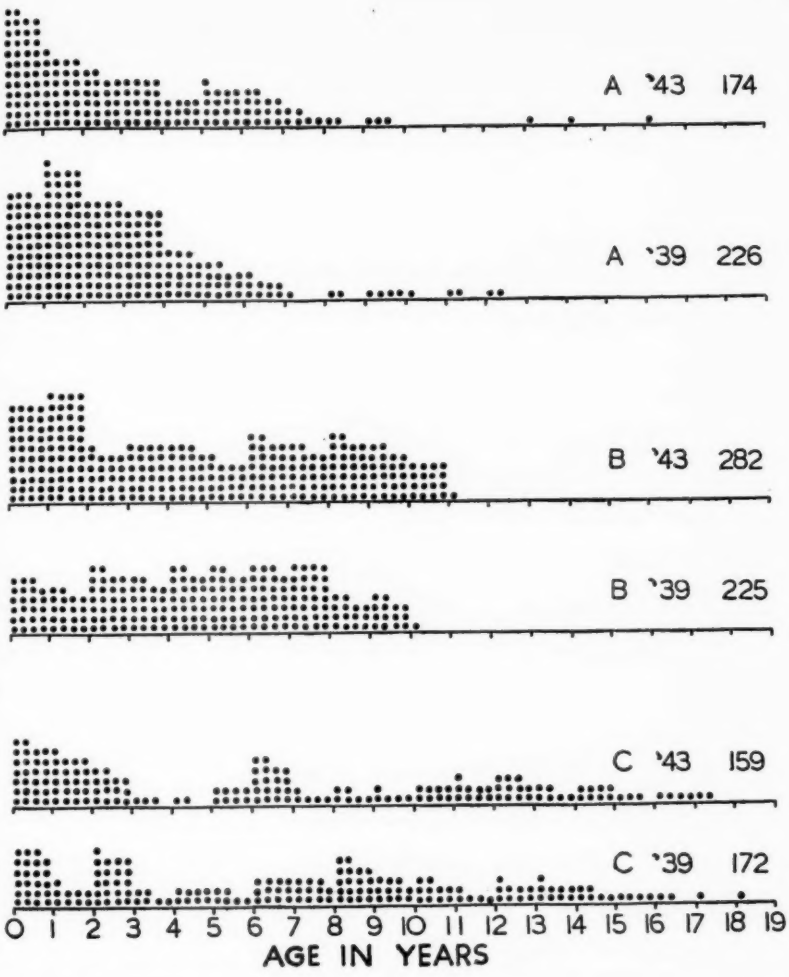
The foregoing estimates are descriptive of the 1939 Red Poll population, but must be applied with caution to other data pertaining to the same or other breeds. Most estimates, including those just presented, are open to some extent to the criticism that allowance is not made for changes in population size. The Red Poll breed was more or less stationary in numbers in 1939 [8], but this is not always so. What effect a change of population size will have on apparent length of productive life will depend on how it is brought about. An increase in the numbers of young animals registered will, for a time, depress the average age and apparent length of life. Such an increase may be more likely to arise from an expansion of a grading-up scheme than from an increased rate of registration of calves from fully pedigreed cows, the latter being probably near its maximum already. A tendency to keep mature cows longer would also result in an increased population but would have the opposite effect on average age and apparent lifetime. Similarly, the effect of a decline in population size will depend on whether it is brought about by a reduction in registrations, disposals of whole herds, a reduction in the number of old cows, or combinations of these.

Table 1 indicates that in the Red Poll breed in 1939 deaths or disposals, such that the animals were lost to the breed, tended to increase with age. The very low figure for the youngest females probably does not reflect the true position since unhealthy or unpromising calves will not be registered. Apart from this, it appears that the custom of breeders was to dispose of about 22 per cent. of their young cows yearly and to increase the rate to about 30 per cent. as the cows got older. Appearances may be

misleading, however, since prior to 1939 the breed had been expanding and had possibly developed what was considered an undue proportion of old cows. A satisfactory estimate of the proportion of aged cows in the Red Poll breed is not easy to obtain, but it seems worth while to make the attempt in view of the claims made for its longevity. Since Buchanan Smith and Robison [6] have considered the number of cows over 12 years of age in their study, the same definition of an aged cow will be used here. Some 4·5 per cent. of the cattle aged 3 years or more and 3·5 per cent. of those aged 2 years or more in the 1939 herd-list were beyond this age. For the sake of comparison with other breeds, what is needed is the number as a percentage of calved cows, but the necessary information for a direct calculation is not available. The required figure must, however, be somewhat over 4 per cent. if the average age at first calving is at least 2·5 years, since there are more animals aged 2–2·5 years than 2·5–3·0 years. If 4·2 per cent. is accepted as being sufficiently near the truth, then the proportion of aged cows in the Red Poll breed was significantly higher ($P = 0{\cdot}02$–$0{\cdot}01$) than that (2·4 per cent.) found 14 years earlier by Buchanan Smith and Robison in 4 other dairy breeds combined. The real difference may be greater since, as will be shown below, registration data show less than the true proportion of young cows. It does not necessarily follow that the Red Poll is genetically superior in constitution and disease-resistance. Of the 4 breeds mentioned, the Friesian was expanding in numbers in 1925, the Jersey and Ayrshire were for the time being stationary, and the Shorthorn was beginning a 10-year period of decline in numbers. How far these facts would affect the proportion of old cows is not known, but it seems likely that the culling of old cows would vary more with changing economic conditions than would that of young stock. Thus 1925 might have been a less favourable year in which to look for old cows than 1939. Further, it is possible that environmental conditions and culling policies may vary between breeds independently of the quality of the cattle.

Within the Red Poll breed, the largest herds seem to have a rather higher proportion of old cows than the rest. Thus among the 27 herds with more than 100 females of all ages it is estimated in the same way as before, that of the calved cows some 5·2 per cent. were over 12 years old. The corresponding percentage for the smaller herds was about 3·5. The chances of survival may not have been better in large herds, but they were mostly long-established and therefore more likely to contain very old cows. No less than 20 of these had been founded at least 12 years before. Of 3,762 females only 5·9 per cent. were purchased and a large majority of the very old cows were home-bred.

Differences in culling policy are manifest in the age-distributions for individual herds large enough to minimize the risks of misinterpretation due to chance variations in the incidence of disease and in sex ratio. Details of 3 herds are given in Fig. 1 including data for 1943 for evidence of continuity of policy. Herd A shows the commonest type of distribution and resembles the breed as a whole. In Herd B culling was apparently very light up to the age of 9–10 years and then suddenly drastic. Herd C contained an unusually high proportion of very old cows, 32 out



Year	Number of: Cows aged 3 or over	Number of: Daughters aged 0–1	Average age of cows: Aged 3 or over	Average age of cows: With reg. daughters
Herd A: 1939	90	43	5·2	5·7
1943	77	46	5·8	5·5
Herd B: 1939	158	23	6·2	6·6
1943	177	40	6·9	5·4
Herd C: 1939	119	23	9·4	9·5
1943	98	26	10·1	8·7

FIG. 1. Distribution of cows and heifers by age in three herds in 1939 and 1943 to show differences in culling policy. The herds are distinguished by letter, year, and herd-size.

of the whole stock of 172 in 1939 being over 12 years of age. From the data attached to Fig. 1 it will be seen that in Herd A most of the heifer calves born must have been registered, since they number about half the cow stock, and, as expected, the average age of all cows is not dissimilar to that shown by those which had registered daughters, that is, about 5½ years. This should approximate to the interval between generations. In Herds B and C only about half the available heifer calves would appear to have been registered, being sufficient presumably owing to the longer life of the cows. Using the average age of all cows as a guide, the interval between generations in Herd C was nearly twice as long as in Herd A. In spite of the possibility in Herds B and C of preferring aged cows as dams of heifers, those selected, especially in 1943, were mainly of average or less than average age for those herds.

To obtain the proportion of recently established herds and the distribution of non-home-bred animals, herds have been classified according to the age of the oldest home-bred females. The resulting data are given in Table 2. The figures indicate that about 14 per cent.

TABLE 2. *Effect of Herd-duration on Proportion of Purchased Female Stock*

	Age of oldest home-bred female (years)				
	0–2	*3–6*	*7–11*	*12–19*	*Total*
No. of herds (per cent.) .	39 (14)	59 (21)	96 (35)	82 (30)	276 (100)
No. of herds with home-bred ♀♀ only. . .	1	2	23	28	54
Av. no. of ♀♀ per herd:					
home-bred . . .	3·2	14·9	34·4	67·5	35·6
non-home-bred . .	9·5	10·1	4·3	3·9	6·2

of the herds existing in 1939 had not been established for more than 2 years, and suggest an annual intake of 7 per cent. and an average herd-duration (in a stationary population) of the order of 14 years. This is at best only a rough guess, but suggests that herd-duration in the Red Poll breed is not very dissimilar from that found in other breeds by Donald and El Itriby [9]. Another 21 per cent. would appear to have lasted about long enough to have produced a few cows with 1–3 lactations. As would be expected, herd-size increased with increasing herd-duration, whilst the proportion of purchased animals decreased. There is probably little justification for separating herds with home-bred cows over 12 years old from those with cows not more than 7–11 years old. Apart from variation in culling policy, it is obvious that very old cows are more likely to be found in a large than in a small herd. In general, it would appear that owing to the number of small herds in the early stages of development, much of the natural increase in cattle numbers must be devoted to expanding herd-size rather than to intensifying selection.

Comparison of age-distributions from herd-lists and heifer registrations.—Since herd-lists are not found in all British herd-books, it is desirable to

know whether an age-distribution obtained from the dates of birth of the dams of registered heifers (the only source of information in some breeds) agrees with those given by a herd-list. The comparison has been made for the Red Poll data of 1939 with the results in brief in Table 3. The two distributions are not, of course, directly comparable, since the herd-lists give animals of all ages, including young stock, whilst the registrations refer only to dams of heifer calves. Moreover, some 2-year-olds will have calved and some will not. The comparison has therefore been limited to the percentage distribution of females 3–4 years old and over. A somewhat greater proportion of cows aged 3–5

TABLE 3. *Comparison of Percentage Age-distributions of Red Poll Females 3–4 years old and over from Herd-lists and Heifer Registrations*

Age	*Herd-lists*	*Registrations*	*Age*	*Herd-lists*	*Registrations*
3–4	24	20	8–10	10	12
4–5	19	17	10–12	6	6
5–6	14	16	12–21	5	5
6–8	22	24			

years as at December 1939 is shown by the herd-lists than by the registrations, which, however, are based on a much smaller number of cows (1,945). Nevertheless, the difference between the two distributions is significant ($P = 0{\cdot}01$). Assuming that the herd-lists give the closest attainable estimate of the actual population, several reasons suggest themselves for the discrepancy. Some of the 3–4-year-old females may not have calved; calves dropped by heifers may be less viable; and breeders, if not registering every heifer calf, may discriminate more against those from young than from old cows. Whatever the reasons, it seems well to consider the possibility that age-distributions obtained from registrations may tend to overstate the proportion of old cows in a population of pedigree cattle.

Only about one-third of the cow population produced registered heifer calves instead of the theoretical half. In round figures, 6,000 cows produced in the year 2,000 registered daughters, leaving 1,000 to be accounted for by death, non-registration, and failure to calve annually. If 10 per cent. of the expected 3,000 do not appear because of an average calving-interval of more than a year, and another 5 per cent. are eliminated by still-births and deaths, the number available for registration would be 2,550—a generous estimate since Lovell and Hill [10] report 4·4 per cent. still-births and 5·5 per cent. abortions in milk-recorded herds in England and Wales. Those actually registered would comprise about 80 per cent. of this total, giving a potential selection differential of $0{\cdot}350\sigma$ [11], or about one-fifth of that theoretically possible by retaining the best 10 per cent. of the bull calves for breeding. It is extremely doubtful if anything like even this much is obtained in practice owing to different standards and lack of objective measures for performance, as well as diversity of aims in herds with independent breeding policies.

Age-distribution of pedigree Ayrshire and Jersey cows.—The material

for this section was obtained from the 1940 herd-books by looking up the dates of birth of those dams whose progeny happened to be registered at fixed points on each page. The ages of 662 Ayrshire and 568 Jersey cows were found in this way, representing 5·8 and 17·4 per cent. respectively of all the dams appearing in the herd-books for that year. The samples obtained should show a fair cross-section of the populations of breeding cows with respect to age, although allowance should be made for a possible under-estimate of the proportion of young cows.

The ages of cows at the time of birth of their daughters, condensed to half-yearly intervals, are shown in Table 4. The average Jersey dam

TABLE 4. *Age-distribution of Pedigree Jersey and Ayrshire Cows at time of Calving their Registered Daughters*

Age in years	*Jersey*		*Ayrshire*	
	No.	*Cum. per cent.*	*No.*	*Cum. per cent.*
1–2	21	4	4	1
2–3	143	29	175	27
3–4	132	52	148	49
4–5	94	69	104	65
5–6	57	79	75	76
6–7	42	86	40	82
7–8	32	92	43	89
8–9	17	95	28	93
9–10	16	98	22	97
10–11	9	99	10	98
11–12	1	..	6	99
12–13	3	..	3	..
13–14	..	..	3	..
14–15	..	..	1	100
15–16	..	..	..	..
16–17	1	100	..	..
Total	568	..	662	..

was 53·8 months old—just 4 months younger than the average Ayrshire dam as a result of earlier first calvings. From the modal calving age of 25–7 months for Jerseys and 31–3 months for Ayrshires, the decline in class-frequencies with age seems to have been more or less parallel. Of the Ayrshires 1·1 per cent. and of the Jerseys 0·7 per cent. were over 12 years of age (cf. Red Polls above). For the present purposes the proportion of dams which are 6 years old or over, that is, old enough to have been tested for performance on 3–4 lactations, is more useful. The appropriate figures for this proportion are, in percentages, 24 for Ayrshires, 21 for Jerseys, and about 44 for Red Polls.

Age of cows in relation to milk-recording and tuberculin-testing.—In compiling the sample data referred to above, note was taken of each cow regarding the practice of milk-recording (Jerseys only) and tuberculin-testing (Jerseys and Ayrshires) in the herd from which she came.

The age-distributions of the sample cows classified according to the available distinctions are given in condensed form in Table 5, in which the

average ages for each group, and also the percentage of cows falling into each of three large sub-divisions covering the whole age-range, appear. With respect to milk-recording, there was a slightly higher average age

TABLE 5. *Average Ages at Calving of Pedigree Jersey and Ayrshire Cows in relation to Milk-recording, Tuberculin-testing, Home-breeding, and Country*

(The columns headed 'per cent. distribution' give the percentages of animals in the age-groups up to 3 yrs., 3–6 yrs., and 6 yrs. and over)

	Jersey			*Ayrshire*		
	Average age (months)	*No.*	*Per cent. distribution*	*Average age (months)*	*No.*	*Per cent. distribution*
M.R.	53·3	450	30–50–20	..	..	..
Non-M.R.	55·7	118	25–50–25	..	..	..
T.T.	52·9	376	31–50–19	56·7	515	27–51–22
Non-T.T.	55·5	192	26–49–25	61·4	147	26–45–29
H.B.	50·2	336	35–48–17	55·1	473	32–47–21
Non-H.B.	58·9	232	21–51–28	64·4	189	16–53–31
England	53·8	568	29–50–21	52·7	137	28–53–19
Scotland	..	..	..	59·1	525	27–48–25

M.R. = milk-recorded; T.T. = tuberculin-tested; H.B. = home-bred.

for non-recorded than for recorded Jersey cows, but the difference is too small to rely on. The corresponding data for Ayrshires are lacking.

Non-tuberculin-tested cows of both breeds together included a significantly higher proportion of old animals than did tested cows. This difference may be due to culling for tuberculosis, to other factors such as milk-recording, which may be more general in T.T. than non-T.T. herds, or simply to the rearing of young stock for sale. The degree of association between milk-recording and tuberculin-testing cannot be adequately tested with the present data since it needs to be considered on a herd basis as well as on a cow basis, but the Jersey data offer some help in the latter respect. As shown in Table 5, 450 out of 568 Jersey cows were in milk-recorded herds, and 376 were in tuberculin-tested herds. If there were no correlation between milk-recording and tuberculin-testing, the proportion of cows which were both milk-recorded and tuberculin-tested should have been approximately $450 \times 376/568^2$, or 52 per cent. In the same way the other combinations can be calculated, giving the following results:

	Expected		*Observed*		*No. of herds represented in sample*
	No.	*Per cent.*	*No.*	*Per cent.*	
M.R. and T.T.	298	52	330	58	165
M.R. only	152	27	120	21	84
T.T. only	78	14	46	8	26
Neither	40	7	72	13	59

In the present sample there is a highly significant excess of animals which are both M.R. and T.T., and also more than the expected number which is neither M.R. nor T.T. Taken in conjunction with the figures in the last column, this fact implies a tendency for milk-recording and tuberculin-testing to be associated, not only with each other, but also with comparatively large herds (cf. 12). Further analysis of the tripartite age-distributions given in Table 5 shows that it is the combination of these factors rather than either singly which affects ages. The 32–50–18 per cent. distribution characteristic of M.R., T.T. herds departs very significantly from the 25–50–25 per cent. approached by each of the remaining types of herd in this breed ($P = 0{\cdot}001$).

In both breeds, non-home-bred cows were of distinctly greater average age than home-bred cows, the reasons for which have been discussed above. The number of animals which had changed owners appears to be rather high, especially among Jerseys, of which 41 per cent. in the sample were not bred in the herd from which their daughters were registered. Many of these (101 out of 232 non-home-bred animals) were obtained from Jersey Island. Even among the Ayrshires, 28·5 per cent. of the dams were not home-bred.

Since only a few Jerseys were kept in Scotland in 1940, comparison of ages in Scotland and England is confined to Ayrshires. In the sample, 21 per cent. of daughters were registered by English herds. This is higher than the 17 per cent. reported earlier [7], but is based on a much smaller sample. The average age of the dams in Scottish herds is considerably higher than that of the English dams, and the difference arises from the greater number of cows over 6 years of age in Scotland. Whether this is due to a higher proportion of comparatively young herds in England, or to some other cause, such as a relatively low wastage rate in Scotland, cannot as yet be determined.

Discussion

Bearing in mind that the estimate of a cow's phenotype in respect of milk-production improves with the number of lactations, although but little after the third [11, 13], it becomes of interest to consider the potential amount of information available (on the average) about the dams of heifers for replacements. From the observed age-distributions an estimate can be made on the basis of regular calving, as shown in Table 6. A smoothed average is given for the combined Ayrshire and Jersey data, which show sufficiently similar age-distributions.

For comparison the Red Poll values are taken from the ages as given by the dams of registered heifers. Since calvings may be at more than 12-monthly intervals, and the dams may frequently fail to complete the lactations starting with the heifers' births, the amount of information implied may well be exaggerated. Nevertheless, the table may serve as a guide to the effect of culling rate on the potential amount of information about the milk-yields of dams of heifers and young bulls. The 1939 breed-differences in culling rates among young cows meant that whilst 25 per cent. of 2-year-old Red Poll heifers had dams with 0–3 lactations, there were 47 per cent. of such heifers in the other breeds. If milk-

recording and tuberculin-testing tend to increase culling among old cows, these percentages would be too low for herds where they are practised. Since milk-recording is not universal even in the purely dairy breeds the actual percentages for each breed are much higher. A substantial proportion of pedigree dairy replacement heifers are

TABLE 6. *Percentage Distribution of Heifers in relation to the Time their Dams spent in the Milking Herd*

Dam's time in milking herd (years)	*Percentage distribution of heifers at*					
	Birth		*1 year*		*2 years*	
	Ayr.-Jers.	*Red Poll*	*Ayr.-Jers.*	*Red Poll*	*Ayr.-Jers.*	*Red Poll*
0–1 . .	28	20	5	3	5	3
1–2 . .	23	17	30	18	14	2
2–3 . .	16	16	22	18	28	20
3–4 . .	10	14	13	18	16	22
4–5 . .	7	10	8	13	9	16
5–6 . .	6	7	7	9	8	11
6 and over	10	16	15	21	20	26
Total	100	100	100	100	100	100

consequently retained with less evidence of their dams' performances than could be desired.

Allied to the problem of securing and using all the relevant data are the questions of obtaining scope for selection and of achieving the most desirable age-composition of a herd. Numerous studies on wastage from disease indicate how much advantage is to be gained from this approach, and suggest, as do some data presented here, that as wastage declines culling for low yield increases. To make the most of this opportunity, such culling should be based on a correct evaluation of milk-yields. The effect on the average age and age-composition of herds will depend on how it is done. This raises the controversy regarding the desirability of keeping old cows. Olbrycht [14] and Dickerson and Hazel [15] have considered the age-composition of pig herds, arriving at the general conclusion that keeping animals beyond the age at which their phenotype can be adequately assessed increases the interval between generations and slows up the annual rate of progress through breeding. Owners of recently established herds who feel that their stock is capable of considerable genetic improvement may maximize progress by keeping their stock young. This could be done by culling heavily after the third or fourth lactation, retaining only the very best of the mature cows. Old herds in which the level of performance is already high cannot be expected to incur the risks of exchanging good mature for unproven stock. In these an age-distribution with a much lower rate of decline in frequency and a higher proportion of aged cows may be justifiable.

To urge breeders that they should aim at longevity in their stock and keep them as long as necessary to prove their quality in this respect is perhaps premature. The observed age-distributions are quite compatible with purely chance elimination in respect of inherited constitu-

tion or longevity, and there is no evidence regarding the degree of heritability of these qualities. There would seem to be some danger therefore, especially in recently founded and but moderately productive herds, that the shadow of longevity may be preferred to the substance of increased milk-production. The breeding and culling policy appropriate to herds of high performance at the zenith of their histories in which bull sales might be imperilled by dam-daughter regression may not be best in the long run for the vast number of herds less fortunately placed.

It is possible, of course, to maintain a high proportion of old cows while keeping down the interval between generations by selecting replacements only from the young cows. The result, however, is merely to reduce the effective size of the breeding herd without the compensation of breeding from old cows assumed to be phenotypically and genotypically superior in longevity or constitution. In this connexion an observation by Fisher and Holt [16] is relevant. Successful phenotypic selection for a character in a mouse-breeding experiment incidentally resulted in a shortening of the interval between generations. Owing to the rapid progress being made, females which began their reproductive life by producing superior litters finished it by producing types relatively obsolete in comparison with those of early daughters. In another line that resisted selection there was no tendency to select early rather than late-born offspring as parents. Once the phenotypes of breeding animals are sufficiently well established, therefore, and a number of progeny from selected parents adequate for replacements is obtained, a loss of time and space (from the genetic aspect) is entailed in keeping those parents longer. This consideration may, of course, be of little weight in herds where improvement by breeding is regarded as of less importance than economy in replacement costs.

Summary

The age-distribution of 11,534 females, being the whole population of pedigree Red Poll cows, heifers, and calves in December 1939, is given. The percentage of non-home-bred animals rose from 1·7 among calves to 40·4 among cows over 15 years old with an overall average of 14·7. This is attributed to the tendency to buy cattle of breeding age rather than calves, and to the high frequency of recently established herds.

Complete expectation of life for calves intended for registration is estimated at 5·5 years, which is in excess of the average age of all females (3·9 years) owing to the low rate of culling at young ages. For cattle aged 3 years or over, the corresponding figures are 3·8 and 3·2 years. Average age in these data, therefore, does not provide an accurate method of estimating length of productive life. The need for considering changes in population-size is emphasized.

Considerable differences between herds in culling policy are illustrated. Extreme cases in large herds lead to estimates of 5·2 and 10·1 years for the interval between generations.

About 14 per cent. of herds in 1939 had no home-bred females older than 2 years, and a further 21 per cent. had none older than 6 years.

Herd-size in the former averaged 12·7 females of all ages (3·2 home-bred) and rose to 71·4 (67·5 home-bred) in herds with at least 1 home-bred cow over 12 years of age.

The age-distribution of the dams of registered heifer calves resembles that of the whole population; but there is a slight yet significant deficiency of 3–5-year-old cows and a corresponding excess of older cows. Distributions obtained in this way are given for pedigree Ayrshire, Jersey, and Red Poll cattle which show that the proportion of cows 6 years old or over are 24, 21, and 44 per cent. respectively.

The effect of milk-recording and tuberculin-testing on age-distribution has been studied in Jersey and Ayrshire data. Both techniques appear to diminish the proportion of old cows. In the Jersey data, cattle subject to both are of distinctly lower average age than the remainder, subject to either alone or neither.

The potential amount of information about the dams of replacement heifers and culling rates are briefly discussed.

REFERENCES

1. N. C. Wright, Wastage in Dairy Cows. Scot. J. Agric., 1933, **16,** 31–40.
2. National Institute for Research in Dairying. Investigation into the Causes of Removal of Cows from Dairy Herds. Yearbook Berks. Milk Rec. Soc., 1933.
3. G. N. Pettit, Wastage, Length of Productive Life, Replacement and Depreciation of Dairy Cows. J. Agric. Sci., 1940, **30,** 485–97.
4. C. T. Williams, Wastage, Replacement and Depreciation in Dairy Herds. Welsh J. Agric., 1943, **17,** 41–5.
5. G. P. Chitty, Report on the Cost of Milk Production, 1941–2, and Observations on Some of the Problems of War-time Milk-production. Harper Adams Agric. Coll. 1943. Dept. Econ., Fmrs. Rept. No. 14.
6. A. D. Buchanan Smith and O. J. Robison, The Average Ages of Cows and Bulls in Six Breeds of Cattle. J. Agric. Sci., 1931, **21,** 136–49.
7. H. P. Donald, Pedigree Bull Production in relation to Bull Licensing. Vet. Rec., 1944, **56,** 252–3.
8. ——, Growth and Distribution of the Pedigree Red Poll Cattle Population in England. Empire J. Expt. Agric., 1945, **13,** 169–83.
9. H. P. Donald and A. A. El Itriby, The Duration of Pedigree Herds in three Breeds of Cattle in relation to Selective Breeding. J. Agric. Sci., 1946, **36,** 100–10.
10. R. Lovell and A. B. Hill, A Study of the Mortality Rates of Calves in 335 Herds in England and Wales (together with some limited observations for Scotland). J. Dairy Res., 1940, **11,** 225–42.
11. J. L. Lush, Animal Breeding Plans. Iowa State College Press, 1943.
12. National Milk Records, Ann. Rept., 1945.
13. J. C. Berry, Reliability of Averages of Different Numbers of Lactation Records for comparing Dairy Cows. J. Dairy Sci., 1945, **28,** 355–66.
14. T. M. Olbrycht, The Statistical Basis of Selection in Animal Husbandry. J. Agric. Sci., 1943, **33,** 28–43, 74–84.
15. G. E. Dickerson and L. N. Hazel, Selection for Growth-rate of Pigs and Productivity of Sows. J. Anim. Sci., 1944, **3,** 201–12.
16. R. A. Fisher and S. B. Holt, The Experimental Modification of Dominance in Danforth's Short-tailed Mutant Mice. Ann. Eugen., 1944, **12,** 102–20.

(Received November 6, 1946)

SOME FACTORS AFFECTING THE ASCORBIC-ACID CONTENT OF TOMATOES IN NEW SOUTH WALES

E. G. HALLSWORTH AND V. M. LEWIS[1]

(Agricultural Chemistry Laboratories, University of Sydney, N.S.W.)

THE occasional results available suggested that the variations in ascorbic-acid content of tomatoes grown in New South Wales were large in comparison with those reported elsewhere. Since tomato production in N.S.W. was greatly extended during the war years to meet the needs of the Allied forces, it became of interest to investigate the factors responsible for these variations.

Reviews of the literature [1, 2] indicate that the data concerning the factors responsible are rather conflicting. In general it could be said that locality had been shown to be more important than variety. The variations in the ascorbic-acid content of the fruit from one locality between different seasons suggested that this variation was due to other factors in the environment rather than merely the nutrient supply from the soil. This is supported by the clear-cut results with tomatoes in culture solution, where lack of nutrients sufficient to produce most obvious deficiency symptoms were still without significant effect on the ascorbic-acid content [3, 4, 5].

Studies of the influence of light intensity, temperature, and other environmental factors recently reported [6] have indicated the importance of the light factor, and afford complementary evidence to that presented here.

In a preliminary communication [7] the present authors drew attention to the very marked effect of the size of the fruit on ascorbic-acid content, and suggested that the influence of some of the other factors—maturity of bush, variety, soil conditions, &c.—might influence the vitamin-content by affecting the light energy received by the tomato fruit in relation to the weight of the fruit itself.

The tomatoes were grown at different localities in N.S.W. in the various years. The average climatic data are given in Table 1.

At Miranda and Hawkesbury the plants were grown in rows, staked, and pruned to 2 or 3 leaders. At Bathurst and Griffith the plants were not staked, and planted 4×4 ft. apart. The plants were grown with spray-irrigation at Miranda, and furrow-irrigation at all the other localities. The Experimental Farm and the River Farm at Bathurst are both parts of the same N.S.W. Government Experiment Farm, but the former is on a red-brown earth on the hill slopes overlooking the town, whilst the River Farm is about 3 miles away, situated on the alluvial flats of the Macquarie River. The soil there is black and rich in nitrogen, and shows many of the features of a chernozem. The experimental work had to be carried out at the River Farm in 1945,

[1] Now an Officer of the Council of Scientific and Industrial Research, Division of Food Preservation, Homebush, N.S.W.

TABLE 1. *Climatic Data*

Locality	*Year*	*Average rainfall annual*	*Average humidity during growing-period*
Miranda	1943	47·5	66 per cent.
Richmond (Hawkesbury Agricultural College)	1944	29·3	64 „
Bathurst:			
Experiment Farm	1943	23·6	63 „
„ „	1944		
River Farm	1945		
Griffith:			
C.S.I.R. Irrigation Research Station	1944, 1946	15·8	53 „

since a prolonged drought was responsible for the loss of all tomato crops at the Experimental Farm proper, the tank from which irrigation-water was normally drawn being completely dry.

Methods of analysis.—All estimations were made by the direct-titration method with 2, 6-dichlorphenol-indophenol, dye solutions being prepared in the manner recommended by Lugg [4].

The extraction procedure consisted initially in grinding about 10 gm. of the tomato with acid-washed felspar and 3 per cent. metaphosphoric acid in a glass mortar. In later work approximately 30 gm. of tissue were macerated with 200 ml. of the extracting solution in a Waring Blendor. In the later work the extracting solution was either 0·4 per cent. oxalic acid or 0·2 per cent. oxalic acid made up in 3 per cent. (by volume) HCl.

Methods of sampling the fruit.—There is general agreement in the literature that the skin is richest in ascorbic acid [8, 9, 10], but its small proportionate weight makes its relatively unimportant. There is, however, little agreement as to the relative ascorbic-acid contents of the flesh and juice. Although the variation between flesh and juice of an individual tomato may be considerable, in these studies it was not found to be consistent in either magnitude or direction (Table 2).

TABLE 2. *Distribution of Ascorbic Acid within the Tomato*

	Ascorbic acid, mg. per 100 gm.	
Sample	*Locular contents*	*Flesh*
1	18·4	30·9
2	11·0	14·4
3	13·7	12·9
4	19·1	19·6
5	14·1	16·9
6	14·5	10·3
7	15·5	9·7
Mean	15·2	16·4

As a result, the 10-gm. sample was cut as a thin strip at right angles to the axis of the fruit and placed in a weighed beaker of metaphosphoric acid. The 30-gm. sample was cut radially, weighed directly and immersed in the acid, the process of sampling and weighing rarely taking longer than half a minute. Except in the storage experiments, all fruit was analysed on the day it was picked.

The sample-size necessary.—Preliminary studies indicated that the minimum number of fruits for a sample was 16. In view of the marked variation in ascorbic-acid content shown between the fruits of different bushes of the same variety growing under the same conditions, in most variety and maturity studies not more than one fruit was taken from each bush to avoid bias in the results.

The problem of what is an adequate sample is considered later in the light of the results obtained. Individual results are too bulky to be published, since in all, some 3,000 separate fruits were analysed.

Effect of the ripeness of the fruit.—To investigate the effect of ripeness on the ascorbic-acid content, fruit at four stages of maturity, viz. immature green, mature green (full size), half-ripe (green almost gone), and fully ripe, were picked from each of 16 plants of the Bonny Best variety growing at Bathurst, and analysed the same day.

TABLE 3. *Effect of Ripeness on Ascorbic-acid Content*

Ripeness	*Mean weight of fruit (gm.)*	*Mean ascorbic-acid content (mg./100 gm.)*	*Sign. diff. (mg./100 gm.)*
Green, immature .	31	29·39	..
Green, full size .	86	36·10	..
Half-ripe . .	89	38·02	3·05 at the 5% point
Fully ripe . .	98	36·91	4·14 at the 1% „

Although the immature fruits are very significantly lower in ascorbic acid than those which have attained full size, once the fruit is fully grown, differences in ripeness have no effect on the ascorbic-acid content. This is in agreement with other recent findings [6].

Effect of storage.—Most reports indicated that no loss of ascorbic acid occurs in tomatoes on storage for periods up to a fortnight. Since, as indicated by the results obtained here, in practically every case the sample size was inadequate to detect small losses, the problem was further investigated.

In the first experiment, Potentate tomatoes were picked at Miranda at the market stage of ripeness during the afternoon, transported to the laboratory, and 16 fruits analysed the next day. The remainder were divided at random into two groups, one stored at 0° C. and the other at 30° C. Periodical determinations were made on each group, 16 fruits being taken on each occasion. The results indicate quite an appreciable loss at both temperatures, more rapid at first, but falling off subsequently.

In the second experiment, tomatoes of the Tatura Dwarf Globe variety were picked from the plots at Griffith and taken straight into

TABLE 4. *Effect of Temperature during Storage*

Time of storage	Ascorbic-acid content (mg./100 gm.)	
	0° C.	30° C.
1 day at room temperature	25·3	
2 days	..	22·4
3 „	22·9	..
5 „	..	21·2
6 „	21·2	..
7 „	..	21·6
9 „	..	20·9
12 „	21·7	..

Difference for significance = 2·9.

the laboratory. Twenty-four fruits were analysed immediately and the remainder divided into two groups, one of which was stored in the dark, and the other stored in indirect light in a single layer on a bench between two windows.

TABLE 5. *Effect of Illumination during Storage*

Time of storage	Ascorbic acid (mg./100 gm.)	
	In light	In darkness
0 days	34·5	34·5
4 „	33·8	32·8
7 „	28·1	26·2

Difference for significance = 3·0 mg.

The loss at the end of four days is therefore not significant, but is quite significant after a week. At present no explanation can be offered for the difference in the behaviour shown by these two samples.

Studies on glasshouse tomatoes.—Tomatoes of the Sans Pareil variety were grown in the glasshouse during the winter of 1943. They were staked and pruned to 1 or 2 leaders, fertilized from time to time with equal volumes of a complete nutrient solution, and the fruit harvested during the spring. All the fruits produced on 6 plants were analysed for ascorbic acid when the last tinge of green colour had just disappeared from the stem-end. In all, 174 fruits were analysed varying from 2 to 177 gm. weight. As Table 6 shows, neither the total weight of the fruit produced per bush, nor the mean fruit-weight of each bush had any influence on ascorbic-acid production.

The position of the fruit on the clutch, or of the clutch on the bush, had no relation to the ascorbic-acid content of the fruit. Where, however, two or more fruits of the clutch ripened at the same time they were found to be very similar in ascorbic-acid content.

The data obtained suggested a correlation between ascorbic-acid content and fruit-weight for the small tomatoes, but not for the larger tomatoes. As has been demonstrated in a preliminary communication [7], the nature of this correlation suggested a surface-area relationship.

The effect of surface-area on ascorbic acid may be related to the amount of light energy received per unit weight of fruit. At the same time it appeared that as the plant increased in maturity, the ascorbic-acid content of the tomatoes increased. One of two factors may have affected this: either during ripening there was a continuous increase in the intensity of the sunlight, or, as the first fruits to ripen are those nearest the base of the plant, they may be more shaded and receive less sunlight. To test these hypotheses a partial regression analysis was carried out, of ascorbic acid on surface-area, on light energy received before picking, and on the maturity of the bush (Table 7).

TABLE 6. *Production of Plants used in Glasshouse Studies*

Plant no.	*Total weight of fruit produced (gm.)*	*No. of fruits*	*Mean weight of fruits (gm.)*	*Mean ascorbic acid (mg./100 gm.)*
I	1,424	34	41·88	20·6
II	1,315	29	45·34	20·8
III	1,276	18	70·84	22·5
IV	1,038	23	45·13	18·5
V	1,355	32	42·35	23·1
VI	1,416	38	37·27	19·6

The light energy received before picking was studied in three ways: (*a*) by including as separate variates the light energy received in each of the 3 weeks preceding picking; (*b*) by including as one variate the light energy received during the 14 days preceding picking; and (*c*) by making the light energy of the week preceding picking the only variate measuring this influence.

The light energy was calculated[1] from the hours of bright sunshine recorded at Sydney, estimating from 12 years' results of the relation between Solar Radiation and the daily Hours of Bright Sunshine. The two-thirds power of the weight was used as an index of the surface-area on the assumption that the tomatoes did not differ greatly from spherical. A quantitative measure of the maturity of the bush at the time of picking each fruit was obtained by counting the number of days since the first fruit on the bush was ripe.

Table 7 shows a negative correlation between surface-area and ascorbic-acid content that is very highly significant. The correlations with light energy either in the first 7 days, or in the first 14 days preceding picking are not significant, though they are approaching significance, P being just over 0·1. The correlation with the maturity of the bush is not significant in any of the analyses, and becomes smaller though not here significantly so, when the light energy received in the 14 days prior to picking is considered. (Treatment ii.)

The coefficients obtained for the light energies are small by virtue of the comparatively small units used to measure them, the numbers of units being in consequence large. Quantitatively, some idea of the influence of the different factors can be obtained by multiplying the

[1] By W. B. Rimmer of the Mount Stromlo Observatory, Canberra.

standard deviation of each factor by the appropriate coefficient, when the standard deviation due to each factor can be obtained in terms of mg. ascorbic acid per 100 gm. of fruit. Table 7 shows that the most important source of variation is still the variation in surface-area (±3·5 mg. per 100 gm.). The light energy received during the previous 14 days now assumes some importance (±2·56 mg. per 100 gm.), whilst maturity only accounts for a variation of 0·28 mg. per 100 gm.

TABLE 7. *Partial Regression Coefficients of Ascorbic-acid Content on Various Factors*

	Regression coefficient (b)	*Ratio of coefficient to S.E.*	*Probability*	*Standard deviation*	*S.D.* × *b* (*mg./100 gm.*)
(i) Maturity of bush	0·03522	0·97	>0·3	15·28 days	0·54
Surface-area	−0·6616	9·02	<0·001	5·32	3·53
Light energy received in 1st week preceding	0·002198	1·55	>0·1	329·15 gm.-cals./cm.²	0·72
Light energy received in 2nd week preceding	0·001523	0·93	>0·3	305·29 gm.-cals./cm.²	0·46
Light energy received in 3rd week preceding	0·001045	0·71	>0·4	303·29 gm.-cals./cm.²	0·36
(ii) Maturity	0·01843	0·62	>0·5	15·28 days	0·28
Surface-area	−0·6577	65·53	<0·001	5·32	3·51
Light energy received in the 14 days preceding	0·006683	1·48	>0·1	382·55 gm.-cals./cm.²	2·56
(iii) Maturity	0·03986	1·38	>0·1	15·28 days	0·61
Surface-area	−0·6542	8·94	<0·001	5·32	3·49
Light energy received in 1st week preceding	0·001305	0·99	>0·3	329·15 gm.-cals./cm.²	0·43

This negative correlation between size and ascorbic-acid content has also been reported for some small fruited species of *Lycopersicum* [11].

Fig. 1 shows the actual ascorbic-acid figures plotted against weight. An attempt was made to correct the ascorbic-acid figures for maturity of bush and light received, using the coefficients from Table 7, but the scatter of the observations was not improved, probably because these coefficients are not significant. The weights were grouped into classes and the mean ascorbic-acid content corresponding to each class was calculated, Curve *A* then being drawn through the means by eye. Curve *B* on Fig. 1 shows how surface-area per gram of weight changes with weight in a sphere. Curve *A* does not follow Curve *B* perfectly, but flattens out more quickly. This effect could be produced by the fact that tomatoes were not perfect spheres. Since, of all geometrical shapes of the same volume, the sphere has the minimum surface-area, any deviation from the sphere would increase the surface-area and, on the present hypothesis, the ascorbic acid. The deviation from spherical form is more marked for the large than the small tomatoes, which would explain

why Curve *A* departs from Curve *B* more markedly as the weight increases.

It has been noted [7] that with tomato weights of over 30 gm. the relationship between size and ascorbic-acid content is no longer so apparent; study of Curve *B* in Fig. 1 shows that this is because with increasing weight the change in the ratio of surface-area to weight becomes increasingly small, and after a certain point negligible.

Effect of maturity of the bush.—If the mean ascorbic-acid content of the fruit from these plants harvested on each day is plotted against the

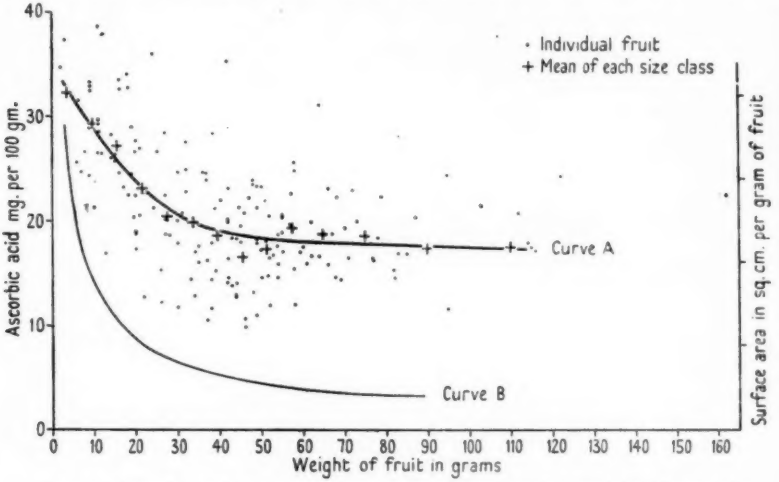


FIG. 1. Ascorbic-acid content of tomatoes plotted against weight (Curve *A*) and surface-area (Curve *B*).

number of days from first picking ripe fruit, there is some tendency for the fruit to increase in ascorbic-acid content as the bush matures (Fig. 2, Curve *A*). This, however, may be affected by both the amount of light energy received in the time before picking, and also by the size of the fruit which decreased somewhat as the fruiting period advanced.

Using the coefficient derived from the regression equation (Table 7, ii), the ascorbic-acid content of each fruit has been corrected for size, and the resulting mean ascorbic-acid contents plotted against the time of picking on the same figure (Fig. 2, Curve *B*). The light energies received during each week are shown on the same graph. As can be seen, the corrected ascorbic-acid contents follow fairly closely the fluctuations in light energy. This demonstrates, as shown in Table 7, that 'maturity' of the bush *per se* has an insignificant influence on the ascorbic-acid content of the fruits.

The amount of light received by a fruit can be affected by foliage as well as by the quantity of light available. Since the age of the plant sometimes has an influence on the amount of foliage present, it would be possible to find an apparent maturity-effect which was really a foliage

effect. This is shown in the results obtained at Griffith, using fruit from bushes sown and planted out at different times.

Since the fruits from all these three sowings were picked and harvested on the same day, the light energy received prior to harvesting was identical in each case. The effect might be explained by the fact that the earliest fruits to ripen are located towards the centre of the bush where they would suffer maximum shade, but as the bush matures, fruits

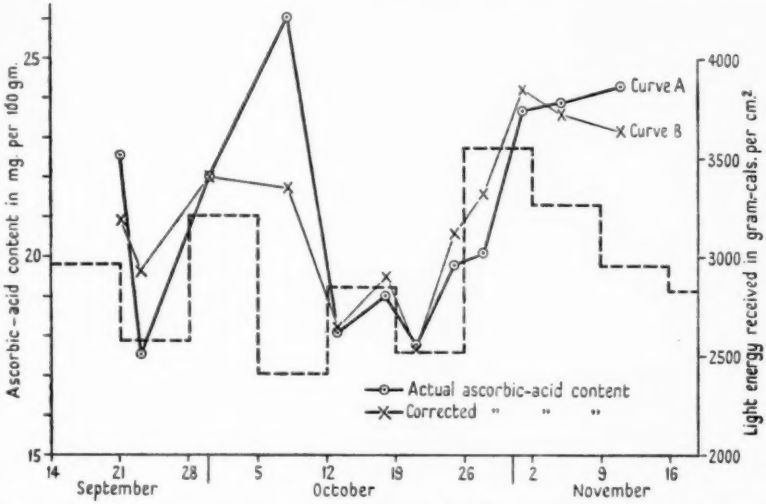


FIG. 2. Ascorbic-acid content of tomatoes plotted against maturity of bush (Curve *A*) and time of picking (Curve *B*).

ripening subsequently are borne progressively toward the extremities of the bush.

TABLE 8. *Effect of Time of Sowing on the Ascorbic-acid Content of Tomatoes*

	Mean ascorbic-acid content	
	San Marzana (*analysed 11.3.44*)	*Tatura Dwarf Globe* (*analysed 14.3.44*)
Sown 5.10.43, planted 23.11.43	35·27	32·89
Sown 18.10.43, planted 10.12.43	34·50	31·13
Sown 1.11.43, planted 21.12.43	23·34	28·23

Difference for significance, at 5 per cent. point, 3·04 mg.; at 1 per cent. point, 4·11 mg.

A similar effect was manifest at Bathurst the following season, with three pickings, from the same bushes, at weekly intervals. It was observed that the fruit at the third picking was much more exposed than the first two.

The first two pickings did not differ significantly, whilst the difference in the ascorbic-acid content of the third picking was highly significant.

TABLE 9. *Effect of Time of Picking on Ascorbic-acid Content of Tomatoes (Rouge de Marmande)*

Picked	Mean weight of fruit	Ascorbic-acid content	
		Mean	Corr. for weight
23.2.45	91·21 gm.	27·24	27·10
2.3.45	97·80 gm.	28·20	28·49
9.3.45	91·27 gm.	40·67	40·52

Difference for significance: at 5 per cent. point, 4·85 mg.; at 1 per cent. point, 6·60 mg.; at 0·1 per cent. point, 8·90 mg.

Bush-to-bush variation.—Another factor resulting in variation of ascorbic-acid content is that one plant may produce fruit with quite different ascorbic-acid content from its row neighbour of the same variety and grown under the same conditions. This factor was allowed for in drawing the samples for the studies on ripeness and maturity. Obviously, if there is a much greater variation between bushes than within bushes, it becomes important to distribute the sample between as many bushes as possible. Moreover, the selection of seed from the bushes producing the fruit of the highest ascorbic-acid content may be a means of enhancing the vitamin-content of the strain.

The existence of the variation was established for the variety Potentate in 1943, and tested on a more extended scale at Bathurst in 1945. The results are given in Table 10.

TABLE 10. *Bush-to-bush Differences in Ascorbic-acid Content*

Variety	Ascorbic-acid content		Fruits per bush for difference to be significant	Variance		Significance of variance ratio
	Mean of variety	Mean of highest bush		Between bushes	Within bushes	
Baltimore .	34·94	39·51	4	85·87	35·58	†
Bonnimar .	38·69	47·78	8	289·62	48·04	•
Bonny Best .	27·79	32·92	..	128·54	67·78	N.S.
					3·21	•
Delvin's Choice	33·31	40·73	8	264·01	23·45	•
Moscow . .	22·98	29·55	8	104·95	22·28	•
Pearson's .	24·93	31·01	16	82·36	40·89	‡
Potentate (1943) .	37·26	45·14	8	112·48	26·06	†
Riverside .	23·94	30·74	4	33·25	9·65	†
Rouge de Marmande .	27·29	32·87	8	62·71	23·40	†
Santa Clara Canner .	24·86	31·23	10	119·82	39·94	‡
Stokesdale .	29·88	38·23	8	272·24	37·94	•

For Potentate, 6 fruits on each of 8 plants were analysed.
For other varieties, 8 fruits on each of 12 plants were analysed.
Significance of variance ratio: • at 0·1%; † at 1%; ‡ at 5% point.

The strain of Bonny Best used was too heterogeneous for the calculation of a mean 'Within-bushes' variance, and the highest and lowest variances are given instead. For all other varieties the bush-to-bush variation was significant, and in some cases highly significant.

Influence of variety on ascorbic-acid content.—This was investigated at Bathurst at the Experiment Farm in both 1943 and 1944, and at the River Farm in 1945.

TABLE 11. *Effect of Variety and Season on Ascorbic-acid Content*

Variety	April 1943		Feb. 1944		Feb. 1945*
	No. analysed	*Ascorbic acid mg./100 gm.*	*No. analysed*	*Ascorbic acid mg./100 gm.*	*Ascorbic acid mg./100 gm.*
San Marzana	16	39·1±1·4	32	36·2±0·9	..
Potentate	16	36·1±1·6	32	39·6±1·0	..
Bonny Best B.E.F.	112	35·2±0·5	128	36·5±0·3	27·8
Bonnimar	12	34·6±2·2	16	33·8±1·2	..
Master Marglobe	16	31·8±2·0	32	41·8±1·3	..
Newell	..	..	16	43·2±1·3	..
Bonny Best No. 8	..	..	32	38·4±1·1	..
San Marzana Inbred	..	..	..	37·8±1·4	..
Break O'Day	..	..	16	36·5±1·1	..
Stokesdale	..	..	16	34·3±1·0	29·9
Tatura Dwarf Globe	..	..	16	31·5±1·1	..
Pearson's	..	..	16	30·8±1·2	24·9
Moscow	..	..	16	28·3±1·3	23·0
Santa Clara Canner	..	..	..	..	24·9
Rouge de Marmande	..	..	..	..	27·3
Baltimore	..	..	..	..	34·9
Riverside	..	..	..	..	23·9
Delvin's Choice	..	..	..	..	33·3

* The difference for significance for these figures is given in Table 15.

Thus in every year there was a significant difference between the ascorbic-acid content of the highest and lowest varieties. The values for the varieties relative to one another are not constant, but between the figures for 1943 and 1944 there is not much difference, except for Master Marglobe. All the varieties used in 1944 were sown again in 1945, but drought caused complete loss of the crop at the main farm, and the results for the River Farm are not strictly comparable. The mean ascorbic-acid content for the five varieties grown in 1943 and 1944 are respectively 35·4 and 37·6, the difference probably not being significant. The means for the varieties grown in 1944 and 1945 respectively are 32·7 and 28·9. This difference, which is significant, includes the variation between the river flat and hill farm, as well as the difference between the two seasons.

Influence of locality.—In an attempt to estimate more accurately the differences due to locality, seed of two strains of Bonny Best, and of an inbred strain of San Marzana were sown in 1943–4 at Bathurst and Richmond, the San Marzana being sown also at Griffith. The results (Table 12) are not strict comparisons, since the plants of Bonny Best at Richmond were grown closer together and were staked, whilst those at Bathurst and Griffith were not. The N.S.W. coast, as exemplified by Richmond, has an earlier season than does Bathurst, on the tablelands, or Griffith, which is in the interior. As a result, the Richmond fruits were analysed relatively late in the season, whilst the Bathurst and Griffith fruits were analysed early.

As can be seen, the difference between Richmond and Bathurst is in every case highly significant, the effect of locality being greater than the maximum difference shown between the different varieties grown at

Bathurst in the same season (Table 11). The various constituent factors of the environment, e.g. water-supply, leaf-area, humidity, light intensity, and quality, need to be studied under controlled conditions before it is possible to suggest the reasons for these differences. That it is more than merely the water-supply (which was restricted at Bathurst in 1944) can be seen in a general way by comparing the figures for the River Farm, Bathurst (Table 11) with those for Richmond, 1944 (Table 12).

TABLE 12. *Influence of Locality on Ascorbic-acid Content*

(*Mean ascorbic-acid content, mg./100 gm.*)

	San Marzana (*6 bushes*)	*Bonny Best* (*16 bushes*)	*Bonny Best No. 8* (*16 bushes*)
Richmond . . .	17·1	18·7	23·3
Bathurst . . .	37·8	36·5	38·4
Griffith . . .	27·9	..	..
Difference for significance between localities	5·5	1·1 at the 5% point	
	8·3	1·4 ,, 1% ,,	
	13·4	2·0 ,, 0·1% ,,	

Influence of leafiness and size of fruit on the ascorbic-acid content of different varieties.—If the ascorbic-acid content of the fruit is affected by the quantity of light energy received per unit weight of the fruit, as has been suggested earlier, one source of the variation shown, both between localities and between varieties, could be the leafiness of the plants. Thus if the soil and water relationships favoured leaf-development, the increased shading of the fruit would diminish the light energy received by them. In the same way a more leafy variety might be expected to have fruits with a lower ascorbic-acid content than a less leafy variety, in which the fruits would be more exposed. In a qualitative manner the results obtained in 1944 supported this hypothesis (Table 11). There was a general gradation in leafiness from Moscow, the most leafy variety, with a mean ascorbic-acid content of 28·3 mg. per 100 gm., to Newell, a spreading, narrow-leaved, open type of bush, with fruit which had the highest mean ascorbic acid recorded for that location and season. At the same time it was observed that the plants grown at Richmond were the most leafy, and those at Bathurst the least leafy, the Griffith plants being intermediate.

If it were possible to obtain some quantitative measure of leafiness, it seemed of interest to test this hypothesis both within and between different varieties. A method used by Haines [13] for measuring tree-health in rubber plantations by photographing the sky visible through the canopy suggested the method adopted.

This was to place four sections of plywood, each 2 × 2 ft., underneath the foliage of the tomato bushes. A 6-in. square was cut out of one corner of each section to accommodate the major stems close to the ground, whilst for smaller bushes sections with only a 3-in. square removed were used. These sections were painted in aluminium paint and stood in marked contrast to the dark green of the foliage. The

bush and square was then photographed from vertically above, at a height of about 10 ft. from the ground. Small divergences from the vertical introduced inappreciable errors. Since the area of the plywood background was constant, it was a simple matter on the print to divide each side into 10 and join the opposite points, thus producing 100 areas. By counting the areas covered by leaves a figure for 'coverage' or 'leafiness' was obtained, expressed as a percentage.

Taking as before, the two-thirds power of the weight as a measure of surface area, the covariance of the $(\text{Weight})^{\frac{2}{3}}$, and the ascorbic-acid content within each variety was worked out. The regression of mean ascorbic acid of the fruit of each plant on the $(\text{Mean fruit-weight per plant})^{\frac{2}{3}}$ and percentage leafiness of each bush was also obtained. The regression coefficients for leafiness were nowhere significant; those for $(\text{Weight})^{\frac{2}{3}}$ are given below (Table 13). The columns headed 'On fruits within bushes' in this table are direct regression coefficients of ascorbic-acid content on $(\text{Weight})^{\frac{2}{3}}$, since leafiness is constant within any one bush. The columns 'On bushes within varieties' contain partial regression coefficients, the effect of different values of leafiness on different bushes having been eliminated.

TABLE 13. *Regression of Weight and Leafiness on Ascorbic-acid Content within Varieties*

Variety	% *Leafiness*	*Weight of fruit*		*On fruits within bushes*			*On bushes within varieties*		
		Range	*Mean*	*Coeff. for* $W^{\frac{2}{3}}$	*S.E.*	*Significance*	*Coeff. for* $W^{\frac{2}{3}}$	*S.E.*	*Significance*
Baltimore	51	31·7–174·5	87·9	−0·3488	±0·1588	At 5%	−0·2135	±0·3633	N.S.
Bonnimar	52	28·0–182·0	93·2	−0·3713	±0·2295	N.S.	1·221	±0·5506	N.S.
Delvin's Choice	63	43·8–289·2	134·7	−0·3193	±0·1070	At 5%	−0·7918	±0·3132	At 5%
Moscow	45	41·4–233·5	108·3	+0·1706	±0·1131	N.S.	−0·4201	±0·2515	N.S.
Pearson's	76	53·2–336·8	153·6	−0·0791	±0·0982	N.S.	..	..	..
Riverside	86	36·5–349·0	148·7	0·0521	±0·0690	N.S.	−0·3708	±0·5180	N.S.
Rouge de Marmande	57	26·3–224·3	94·1	−0·1543	±0·1285	N.S.	−0·7238	±0·1882	At 1%
Santa Clara Canner	100	65·0–434·7	192·9	−0·0461	±0·0807	N.S.	Coverage 100% throughout		
Stokesdale	73	42·5–217·2	101·7	−0·0668	±0·1649	N.S.	−0·2752	±0·0927	At 5%

Considering only the ascorbic acid/$\text{weight}^{\frac{2}{3}}$ relationship within each variety, the coefficients are generally negative, but are significant only for Baltimore and Devlin's Choice. They show a tendency to become smaller as the mean weight of the fruit harvested rises, which confirms the conclusions drawn earlier from Fig. 1. When the influence of the leafiness of the bush is allowed for, the regression coefficient of $(\text{mean weight})^{\frac{2}{3}}$ on the mean ascorbic-acid content becomes negative in every case except Bonnimar. It also has markedly greater dimensions than in the analysis neglecting leafiness, and becomes significant for Devlin's Choice and Stokesdale, and very significant for Rouge de Marmande.

The lack of significance of the partial regression coefficients for leafiness may be due to the small range in leafiness within any one variety. Marked differences in leafiness were shown between different varieties and from the regression equation connecting $(\text{mean weight})^{\frac{2}{3}}$ picking date, leafiness, and ascorbic acid for those varieties with variances suffi-

ciently homogeneous to allow pooling, the coefficients given below were obtained.

TABLE 14. *Regression of Mean Fruit-Size and Varietal Leafiness on Mean Ascorbic-acid Content*

Relationship between ascorbic acid and	*Regression coefficient*	*t*	*Significance*
Size (i.e. $W^{\frac{1}{3}}$)	−2·317	4·24	Almost significant at the 5% point
Picking time	1·250	2·487	Not significant
Leafiness	0·388	3·416	Approaching significance ($P>0·1$)

This result may be considered to disprove the hypothesis that a leafy variety may have fruit of a lower ascorbic-acid content because of the shading effect of the leaves on the fruit. Since in these determinations the importance of the size of the fruit is so great, the vegetative vigour, as manifest by the leafiness, can affect the ascorbic-acid content of the fruit in two opposing ways. It can have a direct, positive effect in increasing the ascorbic-acid content, as indicated by these results. On the other hand, the large fruits, which in these plots were associated with the more vigorous vegetative growth, may exert an overriding effect resulting on the balance in a fruit of lower ascorbic-acid content.

Using the coefficients obtained in this analysis it is possible to determine variety differences uncomplicated by the influence of size and picking time. They are given below (Table 15).

TABLE 15. *Effect of Variety on the Corrected Ascorbic-acid Content*

Variety (*Bathurst 1945*)	*Ascorbic-acid content, mg./100 gm.*		*Diff. for sign.*
	Actual	*Corrected*	
Baltimore . .	34·98	34·67	. .
Moscow . . .	22·98	22·86	At 5% point 2·20
Pearson's . .	24·92	25·21	At 1% „ 2·89
Rouge de Marmande	27·29	27·04	At 0·1% „ 3·69
Santa Clara Canner .	24·86	25·46	. .
Stokesdale . .	29·88	29·70	. .

The difference is clearly not merely due to size and leafiness. Although Pearson's, Rouge de Marmande, and Santa Clara Canner are not significantly different, Moscow is still significantly lower, and Baltimore and Stokesdale significantly higher.

Discussion

In considering the factors affecting the ascorbic-acid content of tomatoes grown in N.S.W., a negative correlation with the size of the fruit has been obtained. The effect of size was most marked with tomatoes weighing less than 30 gm., and is sufficiently large to cast doubts on the value of using the small-fruited tomato species such as *Lycopersicum*

peruvianum and *L. pimpinellifolium* as breeding material in a programme designed to produce varieties of an enhanced ascorbic-acid content. This negative correlation was still found to be significant in certain commercial varieties under field conditions (Table 13). Between the mean ascorbic-acid content and the mean fruit-weight of different varieties it has also been possible to demonstrate a significant negative correlation (Table 14).

Reports in the literature [6] that heavy nitrogenous fertilization depresses the ascorbic-acid content of the fruit require to be considered in relation to the size of the fruit, since this may cause a reduction. The reports of the influence of light intensity on ascorbic-acid production were accompanied by the suggestion that the increased foliage resulted in increased shading of some leaves by others. The results obtained here of the effect of time of planting on ascorbic-acid content rather support this, but the positive correlation obtained between the leafiness and ascorbic-acid content of the six varieties considered, indicates that factors other than shading need to be taken into account. That light intensity before harvest is important is shown by the results for glasshouse tomatoes, the positive correlation between ascorbic acid and the light energy received in the previous 14 days being almost significant (P just over 0·1). This is satisfactory in view of the crudity of the estimate of light energy, and provides further support for the field observations of others [12].

Most reports in the literature suggest that the ascorbic-acid content of tomatoes remains fairly constant for short storage-periods. In these investigations it has been possible to analyse the fruit very soon after their removal from the bush, and perhaps because of this it has been possible to demonstrate a fall. Storage in light or darkness did not significantly affect this decline.

The considerable bush-to-bush variation in the ascorbic-acid content found in this study must be allowed for in all investigations designed to study the influence of different factors of ascorbic-acid content. By drawing samples so that the between-bushes variation could be allowed for, it has been possible to show that after the fruit has attained full size, changes in ripeness have no influence on the ascorbic-acid content, and a significant difference has been shown between fruits of one variety picked at different dates. This is probably a reflection of the differences in light intensity received, but the significant difference between the ascorbic-acid content of fruit analysed on the same day from plants sown at different periods suggests the need for caution in this interpretation, unless the shading referred to earlier affords an adequate explanation. The bush-to-bush variation also offers a means of selection of seed from certain bushes within a variety which would lead to high ascorbic-acid-producing strains, if it can be shown that this characteristic can be inherited.

The necessary difference between the mean of a bush and that for the variety will depend on the number of fruits per bush analysed, increased numbers reducing the error in the usual way. As can be seen from the fourth column of Table 10, for only one of the varieties studied

is this possible with four fruits per bush, 8, 10, or 16 fruits being required for the others.

For selection within a variety it is not necessary to reduce the S.E. of the mean ascorbic-acid content of the variety below 2 mg. per 100 gm., since strains showing a 'within-bushes' variance of the order reported here would require the analysis of 50 fruits from each bush to bring the difference for significance down to 2 mg. per 100 gm. There is thus no risk of loss of material from this source due to wrongful discarding.

Using the method of component analysis the 'within-bushes' and 'true between-bushes' variances have been used to predict the number of fruits on varying numbers of bushes necessary to give the mean for the variety with an error of 2 mg. per 100 gm. At 10 fruits per bush this is obtained by sampling not more than 10 bushes (Table 16).

TABLE 16. *Sample Size and Distribution necessary to obtain a S.E. of the Mean Ascorbic-acid Content of 2 mg. per 100 gm.*

No. of fruits per bush	*Varieties*											
	Baltimore		*Moscow*		*Pearson's*		*Rouge de Marmande*		*Santa Clara Canner*		*Stokesdale*	
	Bushes	*Total sample*	*Bushes*	*Total sample*	*Bushes*	*Total sample*	*Bushes*	*Total sample*	*Bushes*	*Total sample*	*Bushes*	*Total sample*
1	10	10	8	8	12	12	7	7	12	12	18	18
2	6	12	6	12	6	12	4	8	8	16	13	26
3	5	15	5	15	5	15	3 (S.E. 2·1)	9	6	18	11	33
							4 (S.E. 1·8)	12				
4	4	16	4	16	4	16	3 (S.E. 1·9)	12	5	20	10	40
8	3	24	3 (S.E. 2·1)	24	3 (S.E. 2·1)	24	2	16	4	32	9	72
			4 (S.E. 1·8)	32								
10	2 (S.E. 2·05)	20	3 (S.E. 2·05)	30	2 (S.E. 2·2)	20	2	20	4	40	8 (S.E. 2·05)	80
	3 (S.E. 1·75)	30	4 (S.E. 1·75)	40	3 (S.E. 1·8)	30					9 (S.E. 1·95)	90

For studies on the influence of environment the more fruit that can be taken from each bush the better, since this will cover at the same time the influence of fruit-size, and enable the mean weight to be obtained with less sampling error. For the larger numbers per bush the sampling period will inevitably be extended, which will necessitate the measurement of the light energy received both during and for some time before sampling.

Summary

Loss of ascorbic acid from tomatoes on storage is appreciable for a few days, but thereafter the rate diminishes.

There is a significant negative correlation between the weight of the fruit and the ascorbic-acid content, and between the mean weight and mean ascorbic-acid content of the six varieties studied.

Within these varieties there is a positive correlation between vegetative vigour and ascorbic-acid content (P just > 0.01).

A positive correlation between the light energy received prior to harvest that was almost significant (P just $> 0{\cdot}1$), has been obtained. The significant variation that has been demonstrated between the

ascorbic-acid contents of fruit from the same bushes, picked at different times is probably a manifestation of this effect.

The ascorbic-acid content of the fruit is independent of the yield of the bush.

A marked bush-to-bush variation in the ascorbic-acid content of the fruit has been demonstrated in all the varieties studied; also a significant difference among different varieties, although the influence of locality on the ascorbic-acid content has been shown to be greater than that of variety.

Acknowledgements.—The authors are indebted to the Heads and Staffs of the Hawkesbury Agricultural College, Richmond, the Bathurst Experiment Farm, and the Irrigation Research Station, Griffith, for the facilities afforded and for their wholehearted co-operation. For advice and assistance in the statistical treatment of the data, they are particularly indebted to Miss Helen Newton Turner of the Section of Mathematical Statistics, of the Council of Scientific and Industrial Research.

REFERENCES

1. K. C. Hamner and L. A. Maynard, Factors affecting the Nutritive Value of the Tomato. A Review of the Literature. U.S.D.A., 1942, Misc. Pub. No. 502.
2. L. A. Maynard and K. C. Beeson, Some Causes of Variation in the Vitamin-content of Plants grown for Food. Nutr. Abst. Revs., 1943–4, **13**, 155.
3. K. C. Hamner, C. B. Lyon, and C. L. Hamner, Effect of Mineral Nutrition on the Ascorbic-acid Content of Tomatoes. Bot. Gaz., 1942, **103**, 586.
4. J. W. H. Lugg, Aust. J. Expt. Biol. Med. Sci., 1943, **20**, 273.
5. C. B. Lyon, K. C. Beeson, and G. H. Ellis, Effect of Micro-nutrient Deficiencies on the Growth and Vitamin-content of the Tomato. Bot. Gaz., 1943, **104**, 495.
6. K. C. Hamner, L. Bernstein, and L. A. Maynard, Effects of Light Intensity, Day-length, Temperature, and other Environmental Factors on the Ascorbic-acid Content of Tomatoes. J. Nutr., 1945, **29**, 85.
7. E. G. Hallsworth and V. M. Lewis, Ascorbic Acid in Tomatoes. Nature, 1944, **154**, 431.
8. M. N. Rudra, Biochem. J., 1936, **30**, 701.
9. W. A. Maclinn and C. R. Fellers, Mass. Agric. Expt. Sta., 1938, Bull. No. 354.
10. F. Wokes and J. G. Organ, Biochem. J., 1943, **37**, 259.
11. G. B. Reynard and M. S. Kanapaux, Ascorbic-acid Content of some Tomato Varieties and Species. Proc. Am. Soc. Hort. Sci., 1942, **41**, 298.
12. G. F. Somers, K. C. Hamner, and W. L. Nelson, Field Illumination and Commercial Handling as Factors in determining the Ascorbic-acid Content of Tomatoes as received at the Cannery. J. Nutr., 1945, **30**, 425.
13. W. B. Haines, A Method for Foliage Comparisons in Field Experiments with Hevea. Empire J. Agric., 1942, **10**, 117.

(*Received November 22, 1946*)

ARTIFICIAL INSEMINATION IN CATTLE: A REVIEW

JOSEPH EDWARDS[1]

The Spread of Artificial Insemination

THE two wars of the present century are milestones in the spread of breeding by artificial insemination. The end of the 1914–18 war saw fundamental developments in Russia which were the foundation of later progress. In Denmark in 1936 the National Federation of Danish Dairy Associations collaborated with the Danish veterinary authorities in starting A.I. among a large group of heifers segregated on an estate in the north of Jutland. The Federation was engaged on a campaign for the eradication of tuberculosis, and heifer calves, removed from reacting dairy herds at birth, were reared under T.B.-free conditions and returned later in-calf to clean herds. Later in the same year a farmers' co-operative society for A.I. was founded on the Danish island of Samso and its structure and methods came to be followed throughout Denmark and in other countries.

At the outbreak of the late war, and apart from the use of A.I. that was being made in private herds, the movement, in the organized co-operative breeding form that we know to-day, was limited to Russia, Denmark, and the U.S.A. (There was a state organization in Italy, but the results do not appear to have been extensive.) The late war saw further and considerable expansion.

A start was made in England in 1942. In contrast with Russia and Denmark, in which a disease situation provided the initial stimulus, the main cause was the need for the improvement of the country's dairy cattle. This need was revealed by a war-time survey of the nation's dairy herds and by the realization that the bulk of the nation's milk came from small units which, without A.I., would be a constant challenge to improvement by any other methods [1]. About the same time societies were begun in Norway and Sweden and the war period saw developments also in Canada and, on an experimental basis, in New Zealand.

U.N.R.R.A. has played a part in the post-war expansion. Technicians were trained in England during the war and, at its close, scientists from the liberated countries studied first-hand in England and the United States. American scientists helped to form A.I. societies in Greece (1945) and Austria (1946), and equipment was provided for a start in Czechoslovakia. Sorensen of Denmark went to Poland in 1946 to help to organize a nucleus of five main centres and to train personnel for them. The first commercial centres in France began work in 1946 and a start was made also in Northern Ireland and Eire in the same year. In the main the drive has been the need to improve each country's livestock; but in Holland, where the level is already high, the present rapid expansion is due to the wide distribution of trichomoniasis. (In Austria

[1] Head, Dept. of Dairy Husbandry, Milk Marketing Board, Thames Ditton, Surrey, England.

and Czechoslovakia A.I. is to be used in horse-breeding districts to control outbreaks of dourine in horses.)

Scotland and Switzerland are, in fact, the only European countries with important livestock industries in which A.I. has not yet been adopted. In each the breeding interests are opposed to it; in the former it is said that the dairy herds are larger than in England and that their owners have always taken greater interest in the selection of their sires. The number of bull-breeders with an export trade may well be proportionately greater but the concern to breed sound commercial dairy cows cannot be higher than in Denmark, where breeders in the same category are keen supporters of the movement. In Switzerland the opposition of the breed interests is such that the commercial exploitation of A.I. is forbidden by law. It may be used only to control disease, and on each occasion state veterinary approval has to be obtained. Here again there is an important internal and export market for bulls; there is also a highly developed community-bull system well integrated with the activity of the breed societies which is responsible for a high level of stock throughout the country. The view of the breeders is that they wish to preserve in their breeds a balance among the propensities for milk, meat, and work, and that if they adopt A.I. they will reduce the variation in the types of bulls now in use and so risk losing one or other of these qualities.

Pioneer A.I. work in colonial conditions has been done by Anderson [2]. His recent book reviews a field which presents special problems, but one in which, where there is the need to evolve a new breed to suit local conditions, the technique may well prove to be invaluable.

Organization in England

The way in which a new scientific technique is applied in practice may be as interesting as the fundamental studies that give rise to it. A.I. in England might have developed as in Denmark and the U.S.A., i.e. as a spontaneous movement among farmers prepared to finance and organize their own societies. For a variety of reasons this course has not been followed. The spread of the movement has been planned, and the plan is almost complete. One of the reasons is that the start was made during the war and, therefore, at a time when uncontrolled developments might not be in the national interest. Another was the fact that the Ministry of Agriculture became interested in the movement as a means of livestock improvement and as a possible addition to, and improvement on, its Premium Bull scheme. A third and most important reason was the cost of starting a centre. In view of the disease risks and the importance of maintaining the milk-supply the Ministry was not prepared to approve operations based on a stud of bulls kept under ordinary farm conditions. The need to have completely separate buildings for bulls and laboratory accommodation created the need for quite substantial sums of capital.

Overall development in England is controlled by the Central Advisory Committee on Artificial Insemination. The members of this Committee are appointed by the Minister of Agriculture and are selected from the

National Farmers' Union, the Breed Societies, the Milk Marketing Board, and the veterinary profession. There are also experts of the Ministry of Agriculture's own staff on the Committee. The Committee advises the Minister on the issue of licences to operate centres, and, as A.I. cannot be practised (except within private herds) without a licence, this authority permits the Committee to arrange for the orderly siting of centres and to examine the bona fides of the sponsors. A licence may be revoked at any time, and an inspectorate of the Ministry is charged with the responsibility of seeing that satisfactory operating standards are maintained.

In 1944 the English Milk Marketing Board stated its desire to develop the A.I. service on behalf of the milk producers of the country whose interests it serves. Although it does not possess an exclusive right to do so, the fact that it is able to lay out the capital required is one of the main reasons for the large part of the national plan for which it is now responsible. The scope of the plan is shown in Fig. 1. The map defines the extent of existing and projected main-centre development and also the number of sub-centres now operating from main centres. (Sub-centres will increase considerably in number as projected main centres come into operation.) The Ministry of Agriculture operates two main centres (Reading and Ruthin); seven are run by independent bodies formed before the Milk Marketing Board became interested; nine main centres owned by the Board are now operating, and a further thirteen, for which either building is now in progress or sites have been acquired, are projected.

The considerable differences in cow density (seen in the number of cows given in main centre areas on the map) are responsible for the variation in the distances between centres. In the early stages priority in development was accorded chiefly on the urgency of the need for livestock improvement and the disease position (three small centres were started solely to overcome trichomoniasis). Siting is now controlled by the fact that, for health reasons (chiefly the risk of foot-and-mouth disease), no centre may have more than 30 bulls. Assuming an average number of 1,000 cows per bull per annum and an entry of 40 per cent. of the cows in an area in the A.I. scheme, a 'population' of 75,000 cows may be covered by a 30-bull centre. The area that gives this population is described by hatching around each centre (see map) and it is within it that sub-centre development will take place. Although accurate costings are still lacking, it is thought that, in English conditions, an operating radius of 10 miles is near to the economic limit.

Buildings.—The typical 30-bull centre is built on part of a site of 10 acres of land (Fig. 2). It consists of a bull-block (for 15–20 bulls at the outset), an administration and laboratory block, an isolation block and a pair of cottages. The cost, including roads and services, is in the region of £13,000–£15,000. It will be seen that in the bull-block, two-thirds of the accommodation is in the form of 'tie-ups'—the bulls are stalled like cows and lie on a wooden grid floor that gives central drainage. Two bulls can be kept in the space required for one in the remaining loose-box type of accommodation. In addition to economizing space it is said

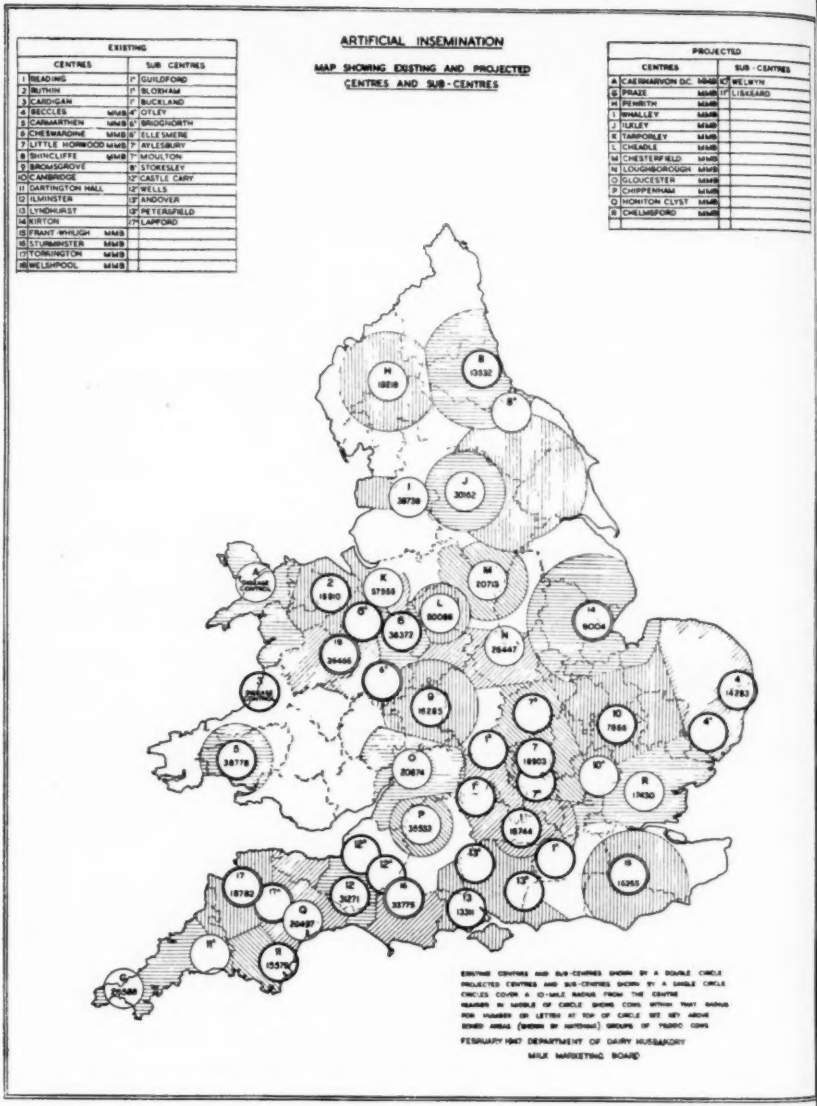

ARTIFICIAL INSEMINATION
MAP SHOWING EXISTING AND PROJECTED CENTRES AND SUB-CENTRES
EXISTING
CENTRES
SUB CENTRES
1 READING
2 RUTHIN
3 CARDIGAN
4 BECCLES MMB
5 CARMARTHEN MMB
6 CHESWARDINE MMB
7 LITTLE HORWOOD MMB
8 SHINCLIFFE MMB
9 BROMSGROVE
10 CAMBRIDGE
11 DARTINGTON HALL
12 ILMINSTER
13 LYNDHURST
14 KIRTON
15 FRANT-WHILIGH MMB
16 STURMINSTER MMB
17 TORRINGTON MMB
18 WELSHPOOL MMB
1* GUILDFORD
2* BLOXHAM
3* BUCKLAND
4* OTLEY
5* BRIDGNORTH
6* ELLESMERE
7* AYLESBURY
7* MOULTON
8* STOKESLEY
12* CASTLE CARY
12* WELLS
13* ANDOVER
13* PETERSFIELD
14 LAFFORD
PROJECTED
CENTRES
SUB-CENTRES
A CAERNARVON D.C. MMB
B PRAZE MMB
H PENRITH MMB
I WHALLEY MMB
J ILKLEY MMB
K TARPORLEY MMB
L CHEADLE MMB
M CHESTERFIELD MMB
N LOUGHBOROUGH MMB
O GLOUCESTER MMB
P CHIPPENHAM MMB
Q HONITON CLYST MMB
R CHELMSFORD MMB
17 WELWYN
17 LISKEARD
EXISTING CENTRES AND SUB-CENTRES SHOWN BY A DOUBLE CIRCLE
PROJECTED CENTRES AND SUB-CENTRES SHOWN BY A SINGLE CIRCLE
CIRCLES COVER A 10-MILE RADIUS FROM THE CENTRE
NUMBER IN MIDDLE OF CIRCLE SHOWS COWS WITHIN THAT RADIUS
ROW NUMBER OR LETTER AT TOP OF CIRCLE SEE KEY ABOVE
BOARD AREAS (SHOWN BY NATIONAL) GROUPS OF PEDIGREE COWS
FEBRUARY 1947 DEPARTMENT OF DAIRY HUSBANDRY
MILK MARKETING BOARD

FIG. 1

by authorities who have experience of tie-ups that the bulls kept in them are most docile and easy to handle.

The amount and kind of exercise which bulls require is still unknown. A loose-box and a run-out or paddock will not make a bull exercise if he does not wish to; mechanical exercisers may be provided and the simple practice of tethering followed almost everywhere in Denmark seems to give good results. It remains to be seen if the mechanical exerciser is essential in mid-winter when land conditions make tethering impossible.

An important feature shown in Fig. 2 is the entry to the buildings. Inseminators returning from work enter through a cleansing-room. They therefore clean themselves, their footwear, and kit before coming into contact with the animals at the centre.

Management of a centre.—There are certain respects in which the management of the M.M.B. centres differs from that of the independent centres, and it is to these that attention will be drawn. The interests of each centre are looked after by an Advisory Committee of farmers elected by the main and sub-centre membership. The functions of the Committee are to stimulate membership, to locate good bulls for purchase by the Board, and to inspect the progeny of the centre's bulls. Central guidance on breeding policy is dealt with more fully later, but it should be said here that central purchasing has much to commend it. Good bulls are hard to find, and a highly competitive buyers' market might easily destroy the main benefit to be derived from A.I. by the commercial producer. A situation in which the wealthier societies secure the best bulls and the less wealthy have to do with less good bulls is also avoided.

The centre's management is controlled by a qualified veterinary surgeon engaged full-time by the Board. He may, if distances permit, supervise more than one main centre, and he is responsible also for sub-centres in his area. He is in charge of clerical staff, stockmen, and inseminators. The last (non-professional men) have to be licensed by the Ministry. As yet there is no training school but one is to be organized, and at it inseminators will learn more of theory and practice than their present grounding in inseminating technique and pregnancy diagnosis. The M.M.B., which is responsible also for the national milk-recording movement, recruits a large number of its inseminators from its recording staff; it is found that the experience of a milk recorder provides a good background for this new work.

The service which the staff gives to members is limited to getting their cows in-calf. There is not, as is very common in Denmark and elsewhere, a sterility service. Yet the fertility records which are kept at the centre's offices are available to private practitioners, and 'problem herds' may be the subject of intensive study by a team consisting of the A.I.-centre veterinary surgeon, the private practitioner, and a member of the Ministry of Agriculture's bovine sterility investigation staff.

There are two administrative aspects of the service which affect its economic efficiency. One is the time allowed for the notification of cows requiring insemination, and the other is the decision which has to be

made to give either a 6-day or a 7-day service. In Denmark and Sweden notification has to be given not later than 10 a.m., whereas in England calls are taken at the central office up to 5 p.m. In Denmark there is

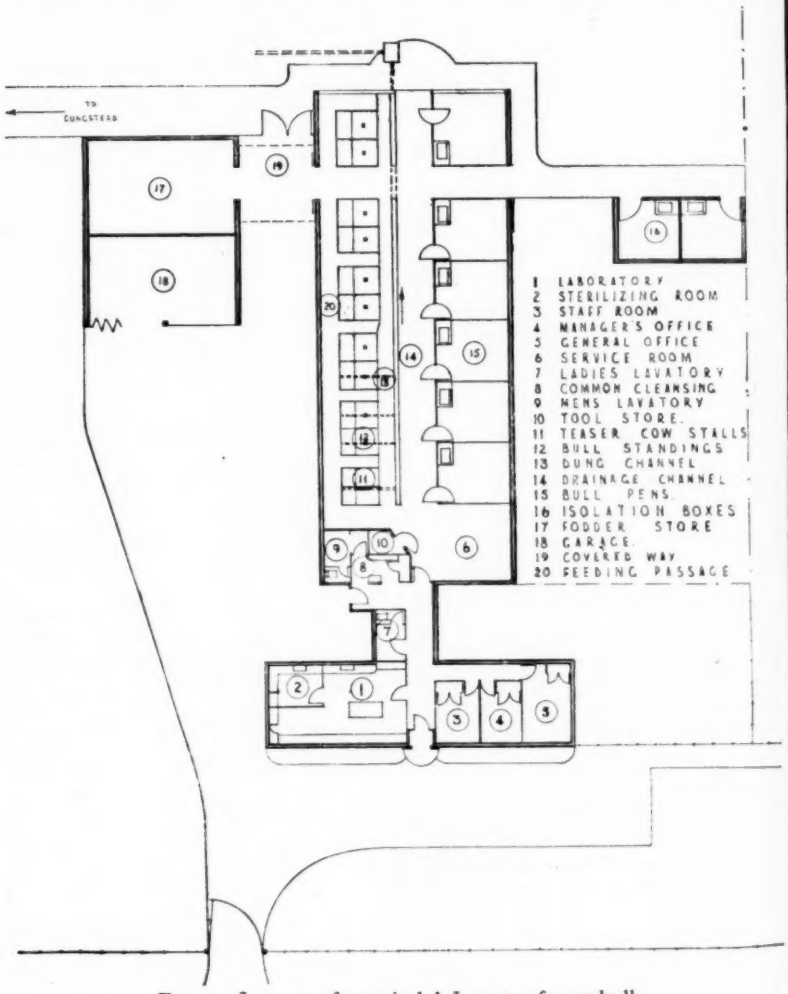


FIG. 2. Lay-out of a typical A.I. centre for 30 bulls.

no service on Sunday and for this reason there is an extension of time for notification on Saturday. In each case the decision must rest on the technical results—the conception-rate obtained. It is apparent that this is not adversely affected by restricting the time for notification, but the effect of the 6-day service is not yet clear. In Denmark a high proportion

of cows that come in oestrus on a Sunday are inseminated on the following day, and, although it is said that there is no obvious difference in the conception-rate, the point is one which requires closer analysis.

Breeding Policy

The sudden expansion of artificial insemination and the evidence that dairy farmers are keen to make use of it alters almost dramatically the positions of the breed society, the animal scientist, and the geneticist, in the structure of the breeding industry. To each it holds out new hopes, and on each it places new responsibility. Since the beginning of the study of genetics the animal-breeder has envied the experimenter with Drosophila, the plant-breeder, and the breeder of small animals for the size of the populations with which each has been able to work and, in the last two categories, the relative ease with which successful experimental methods may be put into practice. He has been aware of the insuperable practical difficulties in the way of the application to the improvement of commercial livestock of even the most obvious method —the use of progeny-tested sires. He may have studied this and other methods of breeding as practised spasmodically in private herds, but he has known that the gap between the successful demonstration and its repetition in wider fields has been a very real one. Now the insemination centre provides a medium for the dissemination of superior breeding stock as extensive as any available to the plant-breeder. The breeder of pedigree livestock may in the past have deplored the fact that economic conditions limited the market for his animals and that, as a result, the breeder of commercial stock could not benefit by their use. The A.I. centre places the best the pedigree breeder has to offer within the reach of all, and breeders and their associations realize, as never before, the emphasis which the new-comers put on qualities of economic importance.

There are many possible breeding plans. From among the experiences of successful practical breeders and the results of controlled experiments there are inbreeding, line-breeding, crossing of lines within breeds, planned cross-breeding, and the use of non-related progeny-tested stock to choose from. The animal-breeder is not yet in a position to say which, if any, is best, and, to judge from differences of opinion between Lysenko and the orthodox geneticists, there are facts of major interest in the field of fundamental genetic theory that await elucidation. Hudson and Richens [3] remark that one of Lysenko's main contentions—that 'from the standpoint of Morganism one can explain anything—but it is impossible to foresee anything with certainty'—is in the main true and that it indicates a deficiency in our present knowledge.

Although, therefore, the animal-breeder cannot present the new cattle-breeding movement with a plan, he has a new awareness of the importance of his science; he knows that, given adequate nucleus stocks, the medium exists for extending their use. Even within the limits of our present knowledge there is much that can be done. There are areas in the world, for example, in semi-tropical and tropical countries, where the need of supplies of fresh milk will call for new dairy breeds. Organized artificial breeding may be used for crossing foundation breeds and to

provide a large field of selection among successive generations of progeny.

In the early days of the movement the fear was frequently expressed that A.I. would lead ultimately to a concentration on a dangerously small number of sires. Factual evidence on this point is only now becoming available, and the best is that provided in Denmark. Table 1 summarizes the cow-and-bull census statistics for three years before the start of A.I. (1934–6) and for the most recent period (1944–6).

TABLE 1. *Effect of A.I. on Number of Bulls in Denmark*

Before A.I.			*Since A.I.*		
Year	*No. bulls*[1]	*No. cows*[1]	*Year*	*No. bulls*	*No. cows*
1934 . .	64,000	1,716,000	1944 . .	56,000	1,555,000
1935 . .	63,000	1,647,000	1945 . .	53,600	1,577,000
1936 . .	65,000	1,616,000	1946 . .	50,000	1,595,000

[1] Bulls = 1 year old or more: Cows = cattle, including heifers, which have calved.

The average number of bulls in use each year in the 1934–6 period was 64,000, and the decrease to 1946 is seen to be 14,000 or 22 per cent. It is known that in 1946 approximately 500,000 cows were inseminated—31 per cent. of the country's cattle population. For this number about 700 bulls or 1½ per cent. of the country's bull population were employed. For the remaining 69 per cent. of the cow population 50,300 bulls (or 98½ per cent.) were used by normal mating. Although this number is likely to be reduced still further, it is apparent that in Denmark, for some time to come, the field of selection for sires will remain a wide one even if the number chosen is small.

It is perhaps too soon to assess accurately the extent to which sire selection for A.I. in any country is becoming concentrated upon a few breeding lines. Yet the number of outstanding breeding units (private or state-owned herds) is limited, and the tendency is evident everywhere to go to them for replenishments. In this connexion there is much to think about in a recent study by Donald and Itriby [4] who have measured the 'duration' of life of pedigree herds in three breeds and the relation of this to selective breeding. It is found, for example, that if 'duration' is defined as the period during which one breeder was in charge, the average 'life' of the herd was 10·6 years for the Ayrshire breed and 9·5 for the Jersey. (Herd transfers, e.g. father to son, extend the average life to 13·4 and 11·4 years.) Of Ayrshire herds established in 1905–12, 24 per cent. were dispersed within the first five years of existence, and among Jersey herds established in 1924–38, 50 per cent. disappeared in the first 5 years and 17 per cent. in the next 5. It is concluded that, under favourable conditions, the average breeder may succeed in breeding 2–3 generations of cattle, and that the lack of continuity must be a serious drawback in constructive breeding. If a superior strain is produced there is a strong probability that it will be dispersed within a short time. It is clear that the location of 'superior germ plasm' in livestock, undertaken in the United States by the U.S. Dept. of Agriculture, is, though excellent in itself, only a first step. The

problem is to keep the superior germ plasm going, and the new reliance of a much increased number of producers on this stock underlines the need.

The foregoing discussion deals with problems of the future; it is also necessary to deal with, and plan for, the present. The urgency of the breeding problem and the methods to be adopted differ with the state of the breeding industry in each country and, in particular, with the size of the gap between the productivity of pedigree stock and commercial stock. A study of the dairy-breeding industry in New Zealand by Candy *et al.* [5] yielded the conclusion that 'the average grade herds in which these [pedigree] bulls have been used now approximate the same level of production as the pedigree stock from which herd sires are drawn', i.e., the gap is practically non-existent, and no further improvement by ordinary methods of sire selection can be expected. This is one of the reasons for a suggested novel approach to the use of A.I. in New Zealand. It is proposed by James [6] that superior progeny-tested sires should be used by A.I. in selected 'nucleus' pedigree herds and that their sons should be made available for use by normal mating in grade herds. (A practical difficulty in the way of developing in New Zealand the kind of A.I. organization in use elsewhere is the fact that the breeding season is extremely short—about 90 per cent. of the cows have to be got in-calf within a period of 3–5 weeks.)

In Denmark the word pedigree simply means that among the pure-bred cattle of each race certain individuals have been selected on the basis of performance and type for inclusion in a herd-book. As previously remarked, there is no obvious breeding-plan beyond the attempt to use the best as revealed by the progeny-test. Yet A.I. centres cannot rely entirely on progeny-tested sires, and in Denmark steps have been taken to test unproved sires. A recent report by Larsen [7] describes a plan now in operation by which groups of daughters by A.I. bulls are tested under standard conditions throughout their first lactations. The plan, although limited for the present to first lactations, is an admirable one for, in addition to the control of milk-yield and butter-fat, accurate measurements of food consumed and changes in live-weight under test are also recorded. These facts may be used to measure the 'lactation drive' of Brody, and may point the way to an appreciation of an aspect of heredity which is bound to be given increasing attention—the inheritance of the efficiency of food conversion.

In England the margin between the productivity of pedigree and commercial herds is thought to be a wide one but, in view of the relatively small proportion of herds that are recorded, it is difficult to make an accurate comparison. If true it gives breathing space to those who have to select bulls for A.I. breeding programmes for, in the absence of machinery available in other countries, selection methods that are almost traditional have to be resorted to. But the machinery is now being constructed in the shape of the Bureau of Records at the Milk Marketing Board [8], and in time superior bull-breeding herds and cow-families will be revealed. In Scotland the Ayrshire Breed Society is building up a similar organization. The overall organization in England is unique

in that the milk-recording movement, the analysis of records for breeding (Bureau of Records), and the major part of the A.I. service, is centred in one organization (the Department of Dairy Husbandry of the Milk Marketing Board). But to revert to the problems of the future remarked upon earlier, the definition of successful breeding systems and the problem of the impermanence of outstanding breeding units still remain to be tackled.

Technical Developments and Research

It is not proposed to review this field at length, for this has been done recently by Henderson [9]. The three chief divisions for investigation remain: (*a*) factors affecting the quantity and quality of semen produced; (*b*) factors affecting storage and dilution of semen; and (*c*) conditions affecting conception in the female.

There is little progress to report in the first of these groups. Edwards [10] showed that hormonal control of spermatogenesis differs from that of fertility in the female, but we are still unable, by feeding or hormone therapy, to influence the production of semen. It may well be that because semen collections are subject to many external influences it is difficult to recognize responses to experimental treatments; if this is so the use of identical twin material [11] seems to point the way to the solution of this difficulty. In the absence of an accurate measurement of rate of production of semen it is impossible to evaluate certain results of feeding trials and other treatments already reported.

There has been considerable progress in the treatment of semen—its storage and dilution. As to the latter, Salisbury [12] continues to extend the frontier. Where 5 years ago a dilution rate of 1 part semen to 5 parts dilutor was thought to be considerable, a rate of 1 : 100 is now found by Salisbury to give equally good results. (At this rate 12,861,000 spermatozoa were injected in 1 c.cm. of the diluted semen.) There is nothing to show that at this rate the limit has been reached although, by its use, the number of cows per bull might be 10,000 to 15,000 per annum. It might be well now to study the effect of using a smaller inseminating dose—say, 0·25 c.cm.—containing the same number of sperm in order to conserve diluting fluid. As yet it is not known if storage at higher dilution rates is less satisfactory than at lower rates. The use of egg-yolk as a main constituent of the diluting medium remains one of the most important advances in sperm storage. When more is known of the biochemistry of semen (and of the properties of egg-yolk) it may be possible to extend the storage period beyond the present limit of 3–4 days. The addition of sulphanilamide [13] and penicillin [14] to the diluted semen has been found to control bacterial and fungal growth without harming the sperm.

Conditions affecting conception in the cow may now be divided into those determined by the male (and the use of the A.I. technique) and those which she herself influences. In the former case there is the question of the best time in oestrus at which to inseminate and the best place in the uterus at which to deposit the semen. (MacMeekan [15] and Holt [16] have shown the superiority of intra-uterine insemination

over the intracervical technique.) But the inherent fertility of the cow remains a problem, and the control of the part played by the male has served to emphasize it. Why is the average conception rate, by normal or artificial breeding, only between 50 and 60 per cent.? The fertility records of the insemination centre provide excellent material for a new approach to this most important aspect of animal health.

REFERENCES

1. J. EDWARDS, The Smallness of Dairy Herds as a Challenge to Livestock Improvement. Farm Econ., 1941, 174–8.
2. J. ANDERSON, The Semen of Animals and its Uses for Artificial Insemination. Imp. Bur. Anim. Breed. & Gen., 1946, Tech. Com.
3. P. S. HUDSON and R. H. RICHENS, The New Genetics in the Soviet Union. Imp. Bur. Pl. Breed. & Gen., 1946.
4. H. P. DONALD and A. A. EL ITRIBY, The Duration of Pedigree Herds of Cattle in Relation to Selective Breeding. J. Agric. Sci., 1946, **36,** 100–10.
5. R. A. CANDY, *et al.*, Sire-survey Work and Herd Improvement through Breeding. N.Z. Dairy Bd., 1943. Nineteenth Ann. Rept.
6. J. P. JAMES, The Relationship of Artificial Insemination to Future Dairy Cattle Breeding. Proc. N.Z. Soc. Anim. Prod., 1946, Sixth Ann. Conf.
7. L. H. LARSEN, Afkomsprøver med tyre. 226. Beretning fra Forsøgslaboratoriet, 1947 (Copenhagen).
8. J. EDWARDS, The Collection, Interpretation and Use of Milk Records. Proc. Brit. Soc. Anim. Prod., 1946.
9. J. A. HENDERSON, Developments in Artificial Insemination of Cattle. Cornell Veterinarian, 1946, **36,** 118–37.
10. J. EDWARDS, The Effect of Unilateral Castration on Spermatogenesis. Proc. Roy. Soc. Ser. B, 1940, **128,** 407–21.
11. G. BONNIER, Studies on Monozygous Twins. Roy. Swedish Acad. Agric., Acta Agriculturae Suecana, 1946, 1: 2, 139–46.
12. G. W. SALISBURY, Fertility of Bull Semen diluted at 1 : 100. J. Dairy Sci., 1946, **29,** p. 695.
13. C. B. KNODT & G. W. SALISBURY, The Effect of Sulfanilamide upon the Livability and Metabolism of Bovine Spermatozoa. J. Dairy Sci., 1946, **29,** 285–91.
14. J. O. ALMQUIST, W. T. S. THORP, & C. B. KNODT, The Effect of Penicillin upon the Livability, Fertility and Bacterial Content of Bull Semen. Proc. Amer. Soc. Anim. Prod., 1946, 38th Ann. Meeting.
15. C. P. MACMEEKAN, N.Z. Dairy Exporter, 1946.
16. A. F. HOLT, Comparison between Intracervical and Intra-uterine Methods of Insemination. Veter. Rec., 1946, **58,** 309.

(*Received February 6, 1947*)

THE EFFECT OF CULTIVATION ON THE GROWTH OF YOUNG TEA

F. R. TUBBS
(*Tea Research Institute of Ceylon*)

THE effect of cultivation upon the growth of tea has been studied in Ceylon by Eden [1], and in India by Cooper [2]. The conclusions reached are in agreement with the conception that the desirable effects of cultivation in the formation of a seed-bed and upon the early growth of the seedling are peculiar to this initial period, cultivation having less effect upon subsequent growth. An investigation on the establishment of young tea commenced in 1938 and, subsequently interrupted by the writer's absence on military service, has since yielded results extending and confirming those already recorded by Eden from established tea.

Cultivation.—The investigation was designed to compare the effect of different types of cultivation upon the establishment and growth of two-year-old seedling 'stumps' in soil from which established tea had been uprooted. The experimental area selected was an even slope, originally *patna* grass-land, upon which tea had been planted in lines at right angles to the contour in 1926. In 1938 these bushes were uprooted, with no more than necessary disturbance of the soil. Three types of cultivation were then applied in lines along the contour, thereby rendering the effects of the uprooting of the original tea, and of its earlier cultivation, common to all three treatments. The experimental arrangement was in 21 randomized blocks, each consisting of 3 cultivated lines separated by 2 rows of untreated soil between the lines. The details of the treatments applied are as follows:

(*a*) *Holing.* Holes were cut 2 ft. apart. They were 18 in. deep and 12 in. wide, tapering to 9 in. wide at the bottom, and were refilled with the soil removed. No disturbance of the soil between the holes in a line took place, save that caused during the removal of the original bushes.

(*b*) *Trenching.* A continuous trench was cut 18 in. deep and 12 in. wide along the length of the line, and the soil subsequently returned.

(*c*) *Forking.* Very thorough 'envelope' forking with 16 in. forks was carried out in strips 12 in. wide along the length of the plot line, the fork being inserted to its full depth.

As in 'envelope' forking the soil is not turned over, treatment (*c*) differed from (*a*) and (*b*) above, in that little mixing of different layers of soil occurred as a result of the treatment. The area was then planted along the cultivated lines with 'stumps' consisting of tap-root and 6 in. of stem only, all laterals being removed. Planting was done with a planting-stick to avoid further soil disturbance, and the bushes were inserted 2 ft. apart along the lines, which were $3\frac{1}{2}$ ft. apart. Cultivation, after planting, consisted in periodic 'envelope' forking of alternate 'rows' (i.e.

areas between pairs of lines), accompanied by the incorporation of green manures and inorganic manures. Alternate rows are denoted A and B. Each set was forked simultaneously on alternate occasions. As cultivation along these rows was not carried out close to the bushes or between bushes in a line, the soil in the lines remained virtually undisturbed. It was also practically free of treading by labour, which normally passed along the rows.

To determine the residual effects upon the soil 8 years later (1946) of the 3 treatments, 5 determinations of the resistance to the movement of a probe through the soil were made in each line, the sites being midway between pairs, chosen at random, of bushes planted in 1938. The data for holing therefore refer to soil which had been undisturbed, save for the pre-1938 cultivation of the area and the uprooting of the original bushes. The figures for trenching may be taken as equally applicable to the soil in the holes in which the bushes in these plots commenced their growth.

The opportunity was taken to make a parallel series of observations on the soil in rows A and B, thereby enabling comparison of the residual effects of the experimental cultivations carried out in 1938 with the accumulated effects of subsequent successive forkings of the rows according to commercial practice. At the time observations were made, rows A and B had each received 5 such forkings since the start of the experiment.

The soil probe used was that designed by Culpin [3], the resistance to penetration being recorded at intervals of 1 in. to a depth of 15 in. The results obtained are shown in Fig. 1, each point being a mean of 105 observations. The data indicated that differences between plots of the same treatment varied with depth; accordingly the data for each of the 15 horizons were analysed separately. Significant differences ($P = 0{\cdot}05$) for each depth are shown above the curves.

Considering firstly the 3 pre-planting treatments, it is apparent that in the first 3 in. consolidation is low and does not vary with treatment. Below this depth the extent to which the trenched soil retained its structure over the intervening 8 years is striking, although there is some evidence of consolidation having occurred below 9 in. in depth. The lesser degree of soil disturbance at depths greater than about 7 in. resulting from forking is also still discernible; the resistance of the forked soil is significantly greater than that of the trenched soil at depths over 7 in., and less than that of untreated soil (holing) to a depth of 10 in. only. This accords with earlier results in which resistance of forked soil to penetration was found to increase sharply at depths greater than 7 in. [1].

The localized and superficial effect of treading upon the soil is illustrated by the curve for row B, which differs significantly from that of the more recently cultivated row A in the first 4 in. only. The untouched soil of the holed lines occupies an intermediate position. Between 4 and 13 in. deep the condition of the rows A and B is the same, and differs from that of the holed lines to a depth of 8 in. only. The effect of the 5 commercial forkings they received is, however, far smaller than that of a single trenching and does not even equal the residual effect of a single thorough forking in 1938.

It is apparent, therefore, that under local conditions only one thorough disturbance is required to produce a lasting effect. The extra care required to obtain real efficiency in a single act of cultivation will achieve superior and more lasting results below the upper 4 in. than will repetitions of less effective operations. Above this depth the value of commercial forking, apart from the incorporation of manures and/or organic

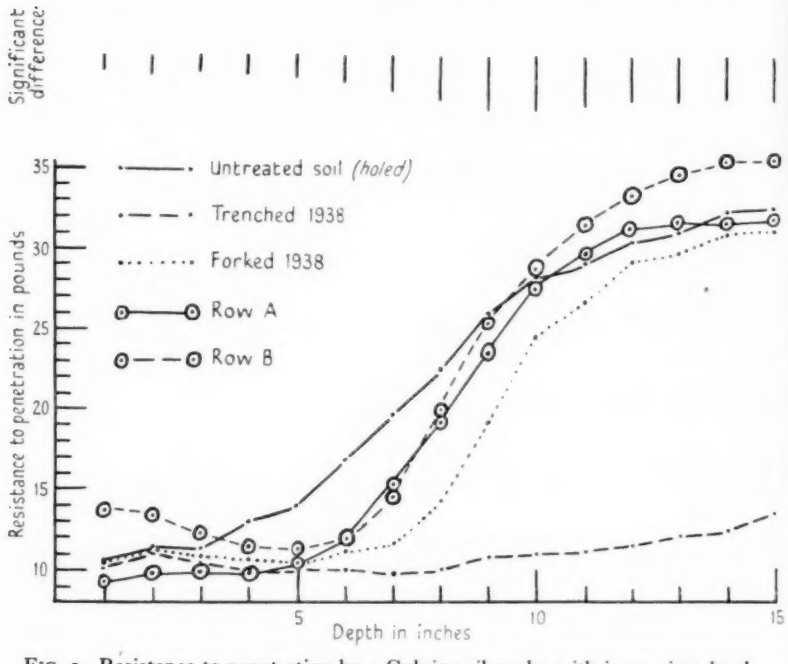


FIG. 1. Resistance to penetration by a Culpin soil-probe with increasing depth, after eight years.

matter, lies in destruction of the superficial pan resulting from the passage of labour through the field.

The difference between rows A and B at depths of 13 to 15 in. is anomalous. It cannot be explained by differences in the efficacy of the cultivation applied, in view of the greater consolidation at these depths in row B compared to the holed lines.

Growth.—The growth of the seedling 'stumps' was followed by records of stem-diameter at the collar made each April and October until 1941, followed by a final measurement in April 1946. Casualties were recorded as they occurred, and were replaced annually with plants which were thereafter excluded from the records. In April 1946 the prunings from each plot were weighed fresh and the root-systems examined. It was not possible to wash the roots from the soil and therefore only an analysis of the gross form of the roots and of their distribution in space was made.

One bush from each plot was carefully excavated with scrapers and small hand-forks. The bulk of the fine laterals were removed intact, but removal was not complete. There is no reason, however, to suspect that any loss that occurred varied with treatment, owing to the large proportion of the root-systems lying outside the soil areas which had received distinct cultivations.

The existence of the marked differences described in the consolidation of the soil immediately surrounding the young plants was found to affect neither the percentage of plants establishing themselves, nor their subsequent growth. Thus, treatment had no significant effect upon the rate of increase in the stem-diameter at ground-level either in the early years or over the total period of 8 years. Similarly no significant difference was found in the weight of prunings or in the total fresh-weight of the roots 8 years after planting (Table 1).

TABLE 1. *Growth Data*

Treatment	*Holing*	*Trenching*	*Forking*
Deaths, per cent.:			
1st year	10·5	12·6	12·4
2nd year	5·7	5·5	5·6
Mean total increase in stem-diameter 1938–46 (in.)	1·40	1·33	1·36
Mean fresh-weight of prunings per bush in 1946 (lb.)	2·32	2·14	2·32
Mean fresh-weight of root-system in 1946 (lb.)	2·20	2·20	2·19

It was possible, however, that the cultivation treatments had influenced the distribution in space of the roots without affecting their total growth; this possibility was accordingly investigated.

The distribution of the roots was measured by recording the quadrant in which occurred the greatest bulk of roots, judged visually, and the longest root, respectively. Two quadrants lay along the line of cultivation, and one each on the uphill and downhill sides of the line. The observations were made separately for two zones in depth: (*a*) from the bush collar to a depth of 12 in., and (*b*) below this. The fresh-weights of roots less than and more than $\frac{1}{4}$-in. thick were then separately recorded for each 6 in. of depth below the collar, the root-stock being weighed separately.

Had root-growth occurred evenly around the root-stock, the number of occasions on which the maximum volume of roots, and the longest root, occurred in each quadrant would have approximated to equality. Marked departures from equality, varying with the treatment, were found, however (Table 2). The significance of these departures, but not the significance of their size, is determinable by the χ^2 test. Significant departures from equality are printed in italics in Table 2.

Comparing the figures for the two quadrants along the line with those of the two quadrants at right angles to it, it is apparent that the plants in the holed plots accorded closely with expectation. There are, however,

TABLE 2. *Direction of Root-growth*

Treatment	*Maximum bulk of roots*				*Longest root*			
	Uphill	*Down-hill*	*Total*	*Along line*	*Uphill*	*Down-hill*	*Total*	*Along line*
Holing:								
Above 12 in. depth	8	3	11	10	7	3	10	11
Below 12 in. depth	1	8	9	12	2	9	11	10
Trenching:								
Above 12 in. depth	7	3	10	11	6	3	9	12
Below 12 in. depth	4	2	6	15	4	5	9	12
Forking:								
Above 12 in. depth	15	0	15	6	15	0	15	6
Below 12 in. depth	3	10	13	8	5	10	15	6
Expected	5·25	5·25	10·5	10·5	5·25	5·25	10·5	10·5

distinct indications ($P = 0{\cdot}05$) of trenching having had an effect below 12 in. in depth upon the location of the maximum bulk of roots. There are also significant departures from expectation in the case of the forked plots. Above 12 in. in depth both the maximum bulk of roots and the longest root occur more frequently in quadrants at right angles to the line, and the same is true below this depth, though here significance is only attained in the case of the longest root. Using the χ^2 test as a measure of independence, the difference in distribution between trenching and forking is significant in each of the four comparisons.

The data in Table 2 also show that there are marked differences in the distribution of roots with depth in those cases where the maximum bulk of roots or the longest root is found in a lateral quadrant. This is particularly noticeable in the forked plots, where the quadrant exhibiting maximum growth was always uphill in the first 12 in. below the collar, whilst below this level it was usually downhill. This effect is also shown in the case of the holing, but not of the trenching treatment.

The differences between the root-systems of bushes from the forked plots and from the other two series of plots, described above, were accompanied by differences in the vertical distribution of the lateral roots, but not in their total amount, as the fresh weights of roots at different levels indicate (Tables 3 and 4). The differences between treatments shown in Table 3 are not significant. By expressing the weight of laterals at

TABLE 3. *Mean Fresh-weight of Lateral Roots (oz.)*

Depth below the collar	*0–6 in.*		*6–12 in.*		*12–18 in.*		*18–24 in.*		*24–30 in.*	
Root diameter	$< \frac{1}{4}$ *in.*	$> \frac{1}{4}$ *in.*	$< \frac{1}{4}$ *in.*	$> \frac{1}{4}$ *in.*	$< \frac{1}{4}$ *in.*	$> \frac{1}{4}$ *in.*	$< \frac{1}{4}$ *in.*	$> \frac{1}{4}$ *in.*	$< \frac{1}{4}$ *in.*	$> \frac{1}{4}$ *in.*
Holed	2·3	4·6	2·0	5·9	1·0	4·2	0·5	0·8	0·1	0·1
Trenched	2·1	3·9	2·1	5·2	1·3	5·6	0·4	0·7	0·0	0·0
Forked	2·1	6·8	2·4	4·7	1·0	3·7	0·4	0·6	0·0	0·0

each horizon as a percentage of the total weight for each bush, differences due to variations in bush-size are reduced, giving the results shown in Table 4. The treatments did not differ significantly in their effect upon the distribution of laterals above and below a depth of 12 in. from the

TABLE 4. *Percentage Distribution of Lateral Roots*

Depth below the collar	*0–6 in.*	*6–12 in.*	*12–18 in.*	*18–24 in.*	*24–30 in.*
Holed . . .	29·5	40·6	23·1	6·1	0·7
Trenched . . .	28·8	38·5	28·4	4·1	0·2
Forked . . .	43·9	32·8	19·4	3·2	0·8

collar, but the bushes in the forked rows had a significantly larger proportion of such roots in the first 6 in. below the collar. By neglecting lateral roots less than ¼-in. thick, which contain a large proportion of ephemeral rootlets, a better picture of the massive structure of the root is obtained. The data (Table 5) again demonstrate that forking resulted in a significantly greater growth in the upper 6 in., the other treatments having more roots in the next three layers, but the difference in no single one of them reaches significance.

TABLE 5. *Percentage Distribution of Lateral Roots thicker than ¼-in.*

Depth below the collar	*0–6 in.*	*6–12 in.*	*12–18 in.*	*18–24 in.*	*24–30 in.*
Holed . . .	27·4	42·7	23·9	5·5	0·5
Trenched . . .	26·5	39·7	30·4	3·3	0·1
Forked . . .	46·1	30·4	20·5	2·6	0·4

No significant differences in the maximum radius of the root-systems as excavated were found to have resulted from the cultivation treatments.

Discussion

The data provide a striking example of the permanence of the effects of a single thorough disturbance upon the structure of a tropical red-brown earth, the effects of which persist for at least 8 years. Eden [1] had already demonstrated that over a period of 17 months no measurable consolidation of untrodden soil occurred, but that in soil regularly trodden by labour at intervals of 7 to 10 days a surface crust formed in the first 2 or 3 in., below which the effects of earlier cultivation persisted. The data for row B of the present experiment (Fig. 1) show consolidation of the same order of magnitude as found by Eden, that in the more recently cultivated row A being much smaller. Owing to the relative absence of treading between bushes in a line, there is little consolidation of the soil between bushes; this is illustrated by the data for the three treatments in which the soil had not been cultivated for 8 years. Rainfall, averaging 94·0 in. per annum over the period of the experiment, did not result in any observable superficial consolidation during the 8 years of the experiment. It is clear that with soils exhibiting such stability of physical condition, frequent deep cultivations serve no useful purpose, and that the effects of one thorough disturbance of the soil are lasting under Ceylon conditions. The inefficiency of commercial 'envelope' forking in achieving deep cultivation is very apparent.

The most interesting feature of the growth data is the absence of any response to more effective, or deeper, disturbance of the soil. The only

differences found are in distribution of growth, not in total amount, and here again the smallness of the effect is remarkable. No significant difference, for example, is found in the distribution of roots in depth between the plants in the holed plots and those in the trenched plots, in spite of the considerable and continued difference in the state of consolidation of the surrounding soil. The distribution in depth of the major roots found in this experiment is in close accord with the distribution of feeding-roots described by Eden [1], and confirms his finding that cultivation, as such, has relatively little effect. Even the greater development of lateral roots in the upper 6 in. of soil in the forked plots may well be because in this treatment there was no admixture of fertile upper soil with the subsoil. This may also account for the tendency of roots to develop along the trench below 12 in. deep in the trenched plots, whereas above this depth there is no such tendency (Table 3).

The importance of local differences in fertility in determining root-growth has been frequently pointed out [4]. In perennial crops, where manuring is relatively superficial, seasonal drought prevents the full expression of this tendency by checking root-growth, or even by causing death of the finer roots, in the uppermost layers of soil. An interesting example is provided by the data shown in Table 2. Plagiotropic lateral roots developing near the collar of the bush encounter fertile soil on the uphill side of the row and speedily reach a depth at which risk of drought injury is lessened. The gradual formation of terraces as a result of erosion and cultivation between the contoured rows of bushes increases this protection. On the lower side of the bush the effect of soil movement is to decrease the thickness of soil above the upper roots. In the course of time, the terraces developed on the surface of the soil thus become mirrored by a terraced distribution of the roots below.

Summary

1. The effect of trenching, holing, and 'envelope' forking prior to planting upon the growth, establishment, and root-distribution of young tea in Ceylon is described.

2. The effects of differences in degree of cultivation upon the state of consolidation of the soil persisted for 8 years.

3. No effects upon growth in size of stems or roots or upon establishment were found. Differences in the distribution of roots with depth occurred, and are ascribed to the effect of local differences in fertility rather than to the stale over-all consolidation of the soil.

4. Natural terracing of the soil was associated with a parallel 'terracing' of the root-systems.

REFERENCES

1. T. Eden, Empire J. Expt. Agric., 1940, **8**, 269.
2. H. R. Cooper, Indian Tea Assoc., Tocklai Expt. Stat., Ann. Rept., 1936, **23**.
3. C. Culpin, J. Agric. Sci., 1936, **26**, 22.
4. J. E. Weaver, Root-development of Field Crops (McGraw Hill).

(*Received November 22, 1946*)

A STUDY OF YIELDS, PREPARATION OUT-TURNS, AND QUALITY IN ARABICA COFFEE

PT. II. PREPARATION OUT-TURNS AND QUALITY

C. A. THOROLD

(*Plant Pathologist, Department of Agriculture, Trinidad; formerly Plant Pathologist, Kenya Colony*)

THE objects of this investigation were to study preparation out-turns and to find if there are characters associated with coffee quality that can be studied quantitatively. Information on the proportional relationship between fresh coffee and the final product was required for a proper understanding of the natural yields considered in Part I (this *Journal*, 1947, **15**, 96–106).

Botanically, the coffee fruit is a drupe with two locules, the outer fleshy part being the pericarp within which is a hard endocarp surrounding each of the two ovules.

Three stages are recognized from picking to the final raw product, as follows:

1. *Cherry*: The ripe coffee fruit as picked and before preparation.
2. *Parchment*: The coffee beans retained within the endocarp.
3. *Clean*: The coffee beans after the endocarp has been removed in the hulling process. This is the condition in which coffee is generally exported. In this stage it is also referred to as *raw* coffee; in opposition to the next stage which is the *roast*.

Methods

1. *Drying.*—The crop usually leaves the estate as partially dry parchment-coffee, the final stages of drying and hulling being completed at an independent factory.

A large number of cherry samples have been carried to the stage of dry coffee and the weights obtained in the parchment and hulled stages. One difficulty arose in deciding on the criterion of 'dry coffee'. In the factory, coffee is dried artificially in bulk, nevertheless the ultimate stage of 'dryness' is somewhat arbitrary. Over-drying tends to cause a loss of colour in the coffee. There is a natural desire to avoid undue loss of weight by excessive drying, therefore drying is only carried to the stage necessary to satisfy the buyer and to ensure against deterioration of the product by moulds or pests during storage. It appeared to the writer quite impossible to rely upon any such subjective character as colour or 'feel' in order to determine the proper stage of dryness for the experimental samples.

The procedure adopted was to dry the parchment and hulled coffee in full sun and to weigh from midday until about 3 p.m., when air humidity is usually at its lowest for the day. Thomas [1] has shown in Uganda that discrepancy may arise unless the humidity of the air at time of weighing is controlled. In the present study a sample was taken as dry when weighings on two successive days, under the above conditions, did

not differ. The parchment and clean-coffee samples could therefore be treated as 'air-dry' weights. This degree of dryness probably exceeds that of most coffee when sold; coffee is hygroscopic when in parchment or hulled and does not remain at a constant air-dry weight when placed in a moist atmosphere. It must be emphasized that the values of the cherry/parchment and cherry/clean ratios to be considered here are probably higher than in estate produce, because the weights of the dry coffee are less than they would be in large-scale preparation. The writer has adopted the expression 'out-turns' in the form of a ratio, rather than as a percentage, because it seems to be the form in which cherry weights can most conveniently be converted to acre-yields of clean coffee. As frequent reference will be made to such ratios later, the expression will be abbreviated by omitting the customary symbol ':1'. Only the figures denoting the number of units of cherry required to give one unit of parchment or clean coffee will be given. Accordingly, the full expression of the ratio as, say, 6·2:1, will be contracted to 6·2.

2. *Weighing.*—The cherry coffee was weighed in the field on a spring-scale but the parchment and clean-coffee samples were weighed in the laboratory to the nearest $\frac{1}{16}$ oz. Only those 'pickings' consisting of 8 oz. or more of cherry were carried to the parchment or clean stages; smaller samples would have given amounts of dry coffee too small for the precision of weighing adopted.

3. *Sampling.*—The cherry/parchment ratios determined for each picking were treated as samples and were combined for individual trees to give the means of these *sample ratios*, and likewise for the cherry/clean ratios. The total weights from all pickings for cherry, parchment, and clean coffee from each tree were combined to give the *bulk ratios*. It is one of the objects of the present study to determine whether these *sample* and *bulk* ratios differ (Table 1). It may be necessary in crop-recording to know in future whether account should be taken of each picking for the individual trees, through sampling for out-turn ratios, or whether bulk determinations are sufficient.

4. *Grading.*—Before sale, coffee beans are generally graded on size, weight, and shape. The last, involving the separation of 'peaberry' and malformed beans, is a procedure applied professionally to coffee in bulk; in the laboratory it is open to subjective determination, which from an 'amateur' in coffee sorting is of little value. Therefore shape of beans could not be conveniently studied and will not now be considered.

Kenya coffee is sold on grades named in order of merit, 'A', 'B', 'C', and others, but this grading is not based on any fixed standards. It has been the custom, in the district where the writer's investigations were carried out, to vary the 'A grade' from year to year. This is not the place to discuss the 'pros and cons' of a non-standard 'A grade'. The fact is stated merely because it influenced the choice of the grade to be adopted for separating 'A's in the present study of coffee out-turns. A sieve with 7-mm.-diameter mesh was ultimately adopted, so that 'A grade' will refer to the beans which were retained by this sieve; no further separation into other grades was made.

5. *Assessment of quality.*—A proper scientific approach to coffee

quality has not yet been attained and is perhaps unattainable. Liquoring is an art, as also to some extent are the other criteria by which the market value of Arabica coffee is assessed. Graded samples were scrutinized by Mr. C. R. Devonshire, Liquorer for the Coffee Board, who assessed the relative merits of the beans as both raw and roasted coffee.

Variation in Out-turn Ratios

1. *Differences between the pickings in one season.*—The main pickings occur at about the same time for the majority of the coffee trees; later, the coffee crop tends to deteriorate towards the end of the picking season. Therefore, there is considerable variation in both quantity and quality of coffee picked during one season. The preparation ratios have been determined and examined for both cherry/parchment and cherry/clean, but only the variability of the first will be considered now. There is considerable variation within the range of values for the cherry/parchment ratio for the different pickings from the same tree. The sample mean is not a weighted average, therefore one large picking will contribute relatively more to the value of the bulk mean, but not so for the sample mean. In consequence, the sample and bulk means may differ significantly, as shown in Table 1.

TABLE 1. *Comparison of Mean Cherry/Parchment Ratio for Individual Trees based respectively on Weights at each Picking (sample) and on the Totals for all Pickings (bulk)*

	1936–7		*1937–8*		*1938–9*	
	Sample	*Bulk*	*Sample*	*Bulk*	*Sample*	*Bulk*
Mean cherry/parchment ratio	5·047	5·006	5·391	5·373	5·239	5·300
Number of individual trees considered	71		157		68	
Difference between the means	0·041*		0·018		0·061*	

* The differences between the sample and bulk means are significant ($P < 0.05$) in two seasons out of the three considered.

2. *Differences between seasons.*—It has been shown that pickings for the same tree in one season may vary significantly in out-turn ratio. It is not surprising, therefore, to find that there is a wide variation in different seasons for the same tree. In some respects the factors responsible for variations between pickings may be regarded as similar to those causing seasonal differences. The picking season generally extends from November until the following March, a period during which the rainfall diminishes progressively, as shown in Table 1 of Part I. When the cherry/parchment ratios for 33 trees in 3 seasons were analysed, it was found that the seasonal variation was much greater than that between trees.

3. *Differences between trees.*—In all the trees sampled for out-turns, both the cherry/parchment and cherry/clean ratios were determined. The difference in weight between the 'parchment' and 'clean' stages is referred to as the hulling loss; it is the most accurately determined factor in the examination of out-turns, because both 'parchment' and 'clean'

samples were weighed on a balance to $\frac{1}{16}$ oz., whilst cherry weights were determined on a spring-scale. Nevertheless, there is variation in both directions from the accepted estate value of a 20 per cent. hulling loss, as shown in Table 2. This has been compiled from 'bulk', as opposed to the 'sample', means. For each tree the total of all the 'pickings' for one season is used as the basis for determining the hulling loss, which is conveniently expressed as a percentage of the parchment coffee.

TABLE 2. *Mean Values, for Individual Trees, of the Percentage Hulling Loss, obtained by the Formula:*

$$\frac{(\textit{bulk parchment} - \textit{bulk clean}) \times 100}{\textit{bulk parchment}} = \text{per cent. hulling loss}$$

	1936–7	*1937–8*	*1938–9*
Mean hulling loss per cent.	21·050	19·190	20·301
Number of trees	71	157	68
Coefficient of variation (per cent.) . .	96	65	90

It is evident that there is an appreciable variation in values of the percentage hulling loss.

A general impression of the variability in out-turns may be conveyed by citing the relevant values for 2 typical trees during 4 consecutive seasons (Table 3).

TABLE 3. *Comparison of Out-turn Data for Two Trees (A and B) in Four Seasons, shown as mean Sample Ratios and mean Percentage Hulling Loss*

	1935–6		*1936–7*		*1937–8*		*1938–9*	
Trees . . .	A	B	A	B	A	B	A	B
Number of samples .	3	4	5	3	8	9	3	4
Cherry/parchment ratio	4·9	4·7	5·0	5·5	5·3	5·6	5·0	6·1
Cherry/clean ratio .	6·4	6·3	6·3	7·6	6·7	7·1	6·3	7·3
Hulling loss (per cent.) .	23·9	26·3	21·4	25·6	20·7	20·3	21·5	17·0

The number of samples is limited, according to the procedure adopted, by the number of pickings which each tree requires. Therefore it may not be possible in this way to obtain an accurate estimate of an out-turn ratio, on account of the variable nature of the samples. On the other hand, when a wide range of data was considered, there was a close approximation to the estate value for hulling loss. It was found on examining all the available individual values, totalling 1,794, that the values for the hulling loss ranged between 10 and 33 per cent., with a mean of 19·76 per cent., which is very close to the accepted estate value of a 20 per cent. hulling loss.

The consideration of out-turns may be concluded by stating that great seasonal differences occur. These can be taken to include both the variation in out-turns for any one tree in the course of the picking-season and the variations for the same tree in several seasons. Therefore, the greatest caution must be exercised in any procedure which attempts to select for multiplication or breeding such trees as appear to have low

out-turn ratios, based on a single season's data. Such differences may be only illusory unless proved over a number of seasons.

The writer noticed only a few trees which have high ratios that exceed the generality by 50 per cent. or more. An example of one of these very poor trees is given in Table 4.

TABLE 4. *Mean Values of the Out-turn Ratios for an Abnormal Tree in Two Seasons*

	Cherry/parchment	*Cherry/clean*
1936–7 . . .	9·0	11·9
1937–8 . . .	8·8	11·2

A few of the Arabica trees which have been under observation have very large berries but these are usually empty. It seems that in such cases an embryo develops but no endosperm is formed; for such trees the out-turn ratios would be almost infinitely large. The occurrence of abortive beans accounts too for trees of other types having high ratios such as that quoted in Table 4. In these abnormal trees the differences from the average will be large for any picking or season, therefore they are readily detected.

Variation of Grades

The consideration of coffee grades is a first step in the study of quality factors, where previously only quantity has been discussed. Although certain quality factors can be defined in quantitative terms, such as size and weight, the difficulty is rather to examine these terms in a way that may be useful in assessing the quality of the coffee, rather than as so many unrelated physical quantities.

When 86 trees were compared in two seasons of generally high and low yields respectively, the mean percentage of 'A's (beans retained by a 7-mm.-mesh sieve) tended to be smaller in the latter but not significantly so.

TABLE 5

	High yields 1937–8	*Low yields 1938–9*
Mean percentage of 'A's. .	20·2	17·5
Difference	2·7 (not significant)	

The correlation coefficients determined for percentage of 'A's and yield were positive but not significant.

Variation in Size and Weight of Beans

It might be expected that differences in the size and weight of beans would account for part at least of the wide variation in percentage hulling loss. Data on bean weights provide some relevant information.

The 'A grade' beans from the produce of each tree were used to obtain a figure for the number of beans in 1 oz. When the 'A

sample' weighed less than an ounce all the beans were counted and then proportionately converted to the equivalent number in 1 oz. When the 'A sample' weighed more than 1 oz., then two or more random subsamples of 1 oz. were taken and counted.

In one season of high yields (1937–8), the correlation coefficient relating the variables percentage hulling loss (*a*) and number of beans in 1 oz. (*b*) is: $r_{ab} = +0{\cdot}247$, which is significant at the 5 per cent. point. The correlation was slightly improved when the effect of percentage of 'A's (*c*) was eliminated, giving the partial correlation coefficient, $r_{ab \cdot c} = +0{\cdot}259$, which is significant at the 2 per cent. point. However, in the next season, which was one of low yields, the total correlation coefficient was insignificantly small. Percentage of A's (*c*) and number of beans in 1 oz. (*b*) were negatively and significantly ($P < {\cdot}01$) correlated in both seasons:

$$r_{bc}\ (1937\text{–}8) = -0{\cdot}460;\ r_{bc}\ (1938\text{–}9) = -0{\cdot}476.$$

Determinations were made of the linear measurements of beans from 7 trees in three consecutive seasons. However, since graded samples were used, large differences in linear measurement could not be expected and none was found. It seemed expedient to determine whether there were density differences existing where there was no consistent relationship between size and weight. Random samples of 20 beans were taken from the graded coffee which had been previously well cleaned and polished by hand. The coffee was then weighed to 0·01 gm. and the volume measured by displacement of xylol in a burette graduated to 0·1 c.cm. The densities were calculated and the values were found to range between 1·137 and 1·258 with a mean value of 1·207. In the analysis of variance of the density values it was found, as with the out-turn data previously considered, that the seasonal variability greatly exceeds that between trees, but the density differences did not reach statistical significance.

Some of the main quantitative characters associated with graded coffee have been considered, namely percentage of 'A's, size, weight, and density of beans. It is important to know whether it is possible to connect any of the quantitative characteristics of coffee so far considered, with quality. The results of the attempt to find such a relationship are described below.

Variation in Quality

'A grade' samples from the same 7 trees harvested in three consecutive seasons, were kept in cellophane bags in a cool cupboard and later submitted to Mr. C. R. Devonshire, Liquorer for the Coffee Board. The samples were examined by him in the raw and after roasting; for both he placed the samples in order of merit, but some were so nearly equal as to be difficult to separate. The procedure adopted was to take the specimens in the order in which Mr. Devonshire placed them and then to allot the numbers 1 to 7, in batches of three, so that for raw and for roast '1' is the best and '7' the worst. The liquorer had no knowledge of the age or origin of the samples which were all presented to him at

random under code numbers. The marks thus awarded (1 to 7) on the raw-coffee samples are tabulated below (Table 6).

TABLE 6. *Marks for Raw Coffee*

Tree	*1936–7*	*1937–8*	*1938–9*	*Mean*
A	7	5	3	5·0
B	7	5	2	4·7
C	6	4	1	3·7
D	5	4	2	3·7
E	7	4	2	4·3
F	6	3	1	3·3
G	6	3	1	3·3
Mean	6·3	4·0	1·7	4·0

In the analysis of variance it was found that the seasonal variation greatly exceeds that for trees and is significant, being nearly 30 times the error mean square. It is to be noted that there is a progressive improvement from the first season, which is the worst. The interpretation, supported by the liquorer's comments, is that the raw coffee loses colour on keeping, hence the inferiority of the oldest and the general superiority of the more recent samples.

After the raw coffee had been examined, samples from each were roasted under standardized conditions and then again placed in order of merit by Mr. Devonshire. The results from his placings for the roasted samples are tabulated below.

TABLE 7. *Marks for Roasted Coffee*

Tree	*1936–7*	*1937–8*	*1938–9*	*Mean*
A	3	7	6	5·3
B	4	3	5	4·0
C	6	5	5	5·3
D	4	4	3	3·7
E	6	7	7	6·7
F	2	1	2	1·7
G	1	1	2	1·3
Mean	3·7	4·0	4·3	4·0

For the roasted coffee the relative positions of 'trees' and 'seasons' are reversed in the variance analysis, compared with that for the 'raw' coffee. This suggests that with respect to the appearance of the 'roasts', coffee does not deteriorate in the same way as it does for the appearance of the 'raws'. This is very valuable because it implies that a liquorer can compare a number of samples for roast under identical conditions at the same time, even though the samples have been gathered over several years. The observation that there is a large and significant 'between-tree' difference with respect to roast in this particular series is most important. Previously, in describing the results of this investigation, every character studied has been found to be more dependent on season than on the tree from which the sample originated. The two coffee trees (F and G) giving the best marks for roast are the only ones grown with natural shade,

which was the tree referred to as 'Musembe' (*Entada abyssinica* Steud.), in describing the investigation of Elgon dieback disease [2]. Trees A and B were growing under artificial shade; the former is the bronze-tip and wide-leaf type resistant to Elgon dieback, whilst B is the green-tip, wide-leaf and high-yielding type, referred to in Table 6 of Part I. All are 'French Mission' trees, with the exception of C, D, and E, which are 'Blue Mountain' trees grown without shade.

An attempt has been made (Table 8) to relate the liquorer's placings with measurements previously determined on portions of the same samples. The 21 pairs of variables are inadequate for the purpose, but the correlation coefficients are given in the hope that they may at least give suggestions as to hopeful lines for further study. It must be pointed out that the correlations in Table 8 have been determined on the 'raw' and 'roast' marks (1–7) in which 'one' is the best and 'seven' the worst. This naturally affects the interpretation of the sign of the correlation coefficient.

TABLE 8. *Correlation Coefficients for Marks on 'Raw' and 'Roast' respectively and Various Bean Measurements and Crop Data*

	Raw	*Roast*
	+0·083	
Percentage of 'A's . . .	−0·449*	+0·074
Number of beans in 1 oz. . .	+0·491*	+0·509†
Mean thickness of beans . .	−0·345	−0·137
Mean length/breadth of beans .	−0·017	−0·377
Mean density of beans . . .	+0·217	+0·411
Yield	−0·291	+0·113
Cherry/parchment ratio . .	−0·119	+0·069
Cherry/clean ratio . . .	+0·108	+0.039
Percentage hulling loss . .	+0·037	+0.019

* Significant, $P < 0{\cdot}05$; † Highly significant, $P < 0{\cdot}02$.

The only correlation high for both 'raw' and 'roast' is that with number of beans in 1 oz. This coefficient is positive in both cases, indicating that the best marks were obtained when there were fewer beans needed to produce 1 oz. of clean coffee.

The samples submitted to Mr. Devonshire were mostly small, and it was found impracticable to carry out any 'cup' tests, such as would have been suitable for inclusion in this study.

Conclusions

One of the objects of the present study was to examine the relationship between the fresh coffee and the final product, for a proper understanding of the natural yields considered in Part I. The study of preparation out-turns leads to the conclusion that a precise factor for converting fresh weights to final product cannot be attained, owing to the great variation in cherry/parchment and cherry/clean ratios for the same tree both during the picking-season and for different years. Therefore, when yields are recorded as fresh-cherry weights, it is sufficient to use some arbitrary factor convenient for ready conversion to acre-yields. In the

special case of an estate where the trees are planted 9 ft. apart on the triangular system, giving approximately 620 trees to the acre, then pounds of cherry per tree may be regarded as equivalent to the same number of hundredweights of parchment coffee per acre, or pounds of cherry per tree multiplied by 100 will give pounds of clean coffee per acre. The latter conversion would be suitable also for trees planted at 8×8 ft. on the square system. However, for 9×9 ft. (square), which is a common planting distance, giving 538 trees to the acre, it would be best to multiply the tree-yield by 100 to give pounds of parchment coffee per acre and then to reduce this by 20 per cent., giving finally pounds of clean coffee per acre.

An attempt to study some of the aspects of coffee quality cannot be said to have contributed much to a subject full of difficulties for any scientific approach. It may be of some value in the future to note that while 'raw' coffee deteriorated greatly in appearance when kept for 2 to 3 years, the same coffee showed no discriminatory disadvantages in appearance when roasted. The appearance of the roast was the only factor which showed a between-tree variation outweighing that attributable to seasons. However, there was also an important environmental difference in that the two trees giving the best marks for roast were grown with natural shade. If it is found that this superiority in quality is a consistant character of shaded coffee, then this advantage may to some extent compensate for the depression of yield through excessive shade which was discussed in Part I of this study and to which attention has been drawn in a footnote by Gillett [2]. As regards the quality of the bronze-tip and narrow-leaf type which has been recommended on account of its resistance to Elgon dieback [2], it is satisfactory to note that this variety which is represented by tree A in Tables 6 and 7, is not markedly inferior to other types and may in 'roast' be equal, or superior, to certain 'Blue Mountain' types, represented by trees C and E in Table 7.

There are indications that 'quality' is to a large extent a varietal character. However, there are evidently certain environmental factors which are important, one of which may be the influence of shade, as explained above. It seems that any possible relationship between soil differences and coffee quality may be rather complex, because the writer has adduced evidence from spectrographic analyses [3] to show that there would appear to be no scope for the direct improvement of coffee quality through the addition of artificial manures to the soil, although there are many ways in which such manures may affect quality indirectly.

Summary

1. The study of preparation out-turns has revealed that the cherry/parchment and cherry/clean ratios and percentage hulling loss vary greatly in different seasons and during the same season for individual trees.

2. Accurate factors for converting 'cherry' weights to 'parchment' or 'clean' are not practicable; therefore such conversions should be carried out by the use of simple and arbitrary factors.

3. The procedure for obtaining the 'A grade' samples is described, together with the determination of other quality factors.

4. Samples have been submitted to a Liquorer who awarded marks for appearance of the 'raw' and 'roast'.

5. It was found that coffee which was stored carefully had not deteriorated after several years with respect to appearance of the 'roast'. This is not the case with clean coffee, judged as 'raw'.

6. The better 'roasts', with which seemed to be correlated a low number of beans to 1 oz., were given by trees grown with natural shade.

7. The produce of a tree representing the type which is resistant to Elgon dieback disease is not apparently inferior to the generality of coffee types.

Acknowledgements (see Pt. I, p. 105).

REFERENCES

1. A. S. Thomas, Some Observations on the Hygroscopic Properties of Dried Coffee Beans and Berries. East Afr. Agric. J., 1937, **3**, 147–52.
2. C. A. Thorold, Elgon Dieback Disease of Coffee. Ibid., 1945, **22**, 203–6.
3. ——, A Note on Results from Spectrographic Analysis of Coffee Material. Ann. Appl. Biology, 1946, **33**, 177–8.

(*Received November 12, 1946*)

THE DEVELOPMENT OF WHEAT VARIETIES IN KENYA

R. J. LATHBURY
(*Department of Agriculture, Kenya*)

Early history.—Wheat was introduced by Missions into the Highlands of Kenya at the end of the nineteenth century. Some years later the early settlers started to grow the crop using mainly Australian varieties, such as Gluyas, Thew, and Bobs; and among them was the late Lord Delamere who was largely responsible for establishing wheat growing. Yields up to 20 bushels per acre were obtained, but by 1908 black stem rust (*Puccinia graminis tritici*) had appeared in the country and the Australian varieties in general use had shown susceptibility to it, though the Italian Rieti, the earliest variety imported, showed resistance. In 1909 Delamere planted 1,200 acres with Rieti only to have the crop destroyed by another species of rust, yellow rust (*Puccinia glumarum*).

Repeated failures to secure suitable rust-resistant varieties by importing seed from wheat-growing countries led Delamere, and then the Department of Agriculture, to employ a plant-breeder, and G. W. Evans was appointed. In 1910 he crossed Rieti with the Australian varieties mentioned above and with Red Fife. Some Egyptian wheats were also utilized because they resisted stem rust. Later, for economy, the Government suppressed the post of plant-breeder, but Evans was again employed by Delamere. On Evans's death the work temporarily ceased, and although no detailed records are available, the hybrids he raised have largely provided the material for subsequent investigations; one variety, Equator, is still grown at the high altitudes because it resists yellow rust.

During the first World War the Government Mycologist, W. J. Dowson [1] carried on the work started by Evans. He, realizing the need of varieties resistant to both black stem and yellow rust if they were to be suitable to all areas of the country, started to raise such wheats as well as continuing work on Evans's hybrids, but his tenure of the post was short and no detailed records of his work are available.

In 1920 G. J. L. Burton [2] was appointed Government Plant-breeder; he inherited the large amount of material raised in the two previous investigations, but many records of the parentage of much of this material was missing, so that the origin of some of the varieties produced from the crosses Burton made with it is unknown.

Soil and climate.—Wheat is grown in the Highlands of Kenya at altitudes between 5,000 and 9,000 ft.; climatic conditions within such a range vary enormously, from sub-tropical to temperate. In general, east of the Rift, as around Nairobi, Machakos, and Mount Kenya, there are two short and widely separated rainy seasons giving two short growing seasons in the year, whereas west of the Rift, that is, west and north-west of Nairobi up to the Uganda border, there is only one, but a much longer rainy season.

In the former area the monsoon rains start at the end of March and give some 15 in. over 2 months, followed by a dry period until the end

of October when further rains fall amounting to some 10–15 in. over 6 weeks. There are thus two distinct rainy seasons in the year in this area and two crops can be grown, though the short or October rains sometimes fail. Altitudes here are mostly low, 5,000–7,000 ft., and owing to the short seasons wheats maturing in 4 months are required.

In the second area west of the Rift rains fall in April and May, followed by further rains in July and August and fewer in November. Rainfall may be said to be ample, and the best crops are usually produced in the drier years, mainly because there is less damage from disease than in wet years. Most of the wheat-growing country is in this area where sowing takes place either in May with harvesting in October, or in July with harvesting towards the end of the year. Altitudes range from 6,000 to 9,000 ft., and owing to the colder climate varieties taking 5 to 7 months to mature are suitable. Altitude affects the period of maturity appreciably: a variety which matures in 4 months at the low levels will require 5 months at the top levels.

Soil conditions vary considerably but in general any fertile land will produce good wheat. Soils are mainly of volcanic origin and may be distinguished from each other by colour differences. Most of the red and brown soils comprising the majority are easy to work and not subject to water-logging.

Seeding, cultivation, and harvesting.—The seed-rate is commonly about 70 lb. per acre. Quick-maturing varieties are mainly seeded at a higher rate, whereas slower varieties, which tiller more, may be sown at a lower rate, particularly at the higher altitudes. Wheat in Kenya tillers profusely and the number of ears to a plant is nearer three than the single ear commonly found in most wheat-producing countries.

Cultivations are very similar to those in other countries and all operations, from seeding to harvesting, are mechanized. The 'combine' is mainly used in harvesting.

Wheat-growing conditions in Kenya are exceptional, as the crop is grown in a climate not far from the Equator, where there are no marked seasons and where sowing takes place over most of the year. Furthermore, night temperatures are low, and although illumination is intense, days are short, so that growth is slow, and spring rather than winter wheats are required. The variety Marquis, for instance, which matures in Canada in under 4 months, takes 5 months in Kenya at 7,000 ft.

Acreage, yields, and prices.—Yields and acreage for 1919–38 and for some of the war years are given in Appendix A. The average yield for the first 10 years was 8·4 bu. per acre and for the second 10 years 10·9 bu. The increase in the second decade may have been partly due to better farming and to more knowledge of optimum dates for sowing and harvesting. The introduction of new rust-resistant varieties, even though these may subsequently have rusted with the appearance of further new races of stem rust, and the growing of the varieties most suited to the different districts, have also made for increased yields. The use of land that is marginal or unsuitable for wheat-growing has, however, been a factor in depressing yields. By 1928 the increased acreage provided a surplus over East African requirements and an export trade began. This trade

proved uneconomic at the world prices then existing and acreages dropped sharply after 1930. The exceptionally small areas sown in 1932 and 1933 was partly due to the invasion of locusts. When stabilization was reached with about 50,000 acres in 1935, the country was largely self-supporting, and did not export. During the late war the acreage has steadily increased (*see* Appendix A). The highest yields have come from the high-altitude districts, and for the period 1942–5 the Mau and Molo area (altitude 8,000–9,000 ft.) averaged 23·5 bu. per acre.

The wheat crop is marketed by a co-operative wheat pool. Prices have depended on the amount produced in excess of local requirements, all of which has to be exported at the prevailing world prices. The industry is protected by a heavy tariff on all imported flour.

Baking quality.—Kenya wheats may be classed as of moderate quality. The country largely depends on wheat grown locally for internal consumption and the miller, baker, and housewife between them have succeeded in producing a palatable loaf of bread.

Most varieties have a high protein-content but have low diastatic power, which can be corrected, and some of them tend to show excessive 'stability' in relation to their general strength. Kent Jones [3] considers the dough characteristics to be better than those of most African wheats and more like good Australian. He gives the moisture-content as varying from 11·5 per cent to 13·0 per cent. with an average of 12·0 per cent., and the protein-content as normally about 10·5 per cent., though some types are considerably stronger and more glutinous. Of recent years the protein-content has been considerably higher with samples up to 16 per cent.

High-quality wheat can be produced, and the Canadian variety Reward grown in Kenya has been classed as the equal of No. 1 Manitoba, as have several Kenya hybrids which have, however, had to be discarded for other reasons. Except for a small acreage of Reward grown in an area that often escapes serious rust damage, there is no really strong wheat grown at present, and the mills would welcome 15 per cent. of such a wheat in their blends. A general indication of the strength of all new hybrids is obtained by the use of Pelshenke's wholemeal-wheat fermentation-time test, and samples of any wheats subsequently increased are sent to England for analysis through the courtesy of Messrs. Unga Ltd. This company was started in 1908 by Lord Delamere, when the first flour mill was erected in the country; to-day it possesses large mills, equipped with modern machinery, at Nairobi and Eldoret.

The atta trade[1] is an important one and the millers do not like to use more than 50 per cent. of red-skinned wheats in their mixtures. Attention has, therefore, been given in the newer crosses to white-skinned wheats.

The rust problem.—Up to 1926 stem rust had mainly been recorded at the lower altitude of 5,000–7,000 ft., the amount of damage varying from

[1] Atta is a type of flour used in making *chapattis*, which takes the place of bread in the Indian diet. As part of the skin of the wheat berry is utilized in the milling process, white rather than red wheats are required to avoid coloration of the flour.

slight to total loss. At the higher altitudes stem rust had been observed but it had not damaged the crop. In 1928 the variety Equator generally grown at the top heights was badly attacked by stem rust, some fields being destroyed. Subsequently stem rust has been present over the whole of the Kenya Highlands irrespective of altitude, and damage at the high altitudes has been as severe as at the lower levels. Any variety of wheat therefore, wherever grown, must possess resistance to stem rust, which implies resistance to all the different strains or physiologic races of stem rust found in the country. Seven different races have been discovered in Kenya to date.

At elevations over 7,000 ft. yellow rust is also present, which becomes more severe with altitude. A suceptible variety may be slightly affected at 7,000 ft. and badly damaged at 8,000 ft., whereas a more resistant variety would only be slightly affected at 8,000 ft. but more severely attacked at 9,000 ft. Attack is severe in the colder districts, where crops may be destroyed.

A third species, leaf rust, is like stem rust prevalent throughout the Colony. It has caused considerable damage, more particularly at the lowest altitudes, but it is not usually so destructive as the other two species.

Wheats, at whatever elevation they are grown, should therefore possess resistance to stem and leaf rust, to which should be added resistance to yellow rust at the higher altitudes.

Physiologic races of stem rust.—From 1921 to 1927 Burton [2] observed that the rust-resistance of some wheats was not constant from season to season, which led him to suspect the presence of more than one physiologic race of stem rust. E. C. Stakman *et al.* [4] had already discovered the existence of numerous physiologic races of *P. graminis tritici*, and in 1928 MacDonald [5] showed that two different races of stem rust were present in the Colony. These two races were designated K. 1 and K. 2. Subsequently a third race, K. 3, was isolated in 1930, a fourth race, K. 4, in 1931, a fifth race, K. 5, in 1936, a sixth race, K. 6, in 1940, and a seventh race, K. 7, in 1943.

Stem rust would appear to be maintained in Kenya through the uredospore stage: wheat is grown over most of the year and there are no marked seasons. A species of barberry (*Berberis Holstii*) is indigenous in certain areas of Kenya, but MacDonald considered that the rust present on the local barberry was not connected with stem rust of wheat, so the possibility of new races arising through hybridization would seem unlikely. It is, however, possible that wind-blown spores from Abyssinia might account for the arrival of new races, as apart from the indigenous varieties already present, the Italians doubtless introduced many new varieties during their occupation of the country.

No work has been done on the isolation of physiologic races of the other two species of rust and, in general, observations on the reactions of varieties to these two rusts in any one season have formed a fairly reliable guide to their behaviour in others. For both species there have, however, been seasons in which the behaviour of varieties has suggested the presence of more than one race of these rusts.

Breeding for Rust-resistance

From 1921 to 1926 one plant-breeder only was employed, who was stationed near Nairobi at 5,700 ft., with a sub-station at Njoro, 7,100 ft. In 1927 the writer was appointed as a second plant-breeder to ensure continuity of work, and from 1933 assumed responsibility for the whole of the wheat-breeding work. A new main station was established at Njoro in 1927 for general-purpose wheats with sub-stations near Nairobi for quick-maturing low-altitude wheats, and at Mau Summit, 8,400 ft., for high-altitude wheats. The latter station was subsequently moved to Molo, 9,100 ft. as being a more severe testing ground for yellow rust.

Since the appearance of several physiologic races of stem rust in Kenya in 1928, resistance to each new race of rust as it appeared has had to be found. Seedling-inoculation tests have therefore been carried out by the pathological section on all material submitted by the plant-breeder, and any resistance carried by Kenya wheats has mainly been a physiologic one based on their seedling reactions. The mature-plant type of resistance, discovered in Canada [4], was not fully effective under Kenya conditions, and reliance had therefore still to be placed on the physiologic resistance as shown by seedling reactions. The Canadian wheats Regent RL 975·6 and Apex RL 1857 which possess mature-plant resistance in Canada are also resistant to most of the Kenya races of stem rust in the seedling stage.

The Pathological Section identifies the K races found in the field crops every year. This rust-survey has shown that the appearance of a new race is generally followed by an epidemic of that form until it is displaced by the arrival of a further new race, although the latest race, K. 7, was first isolated in the breeding-cages and has not yet been recorded in the field in Kenya. Its presence was, however, recorded in Tanganyika Territory in 1945. The spread of any K race also depends on the acreage under varieties susceptible to it. Race K. 2 has always been isolated in the annual rust-survey and has been associated more particularly with the higher altitudes, where the variety Equator, which is susceptible to it, has always been grown. Resistance to this race K. 2 has been more difficult to obtain than resistance to the other races, and the early Njoro hybrids which were originally considered resistant have subsequently been found to show some susceptibility to this race, which explains the lack of resistance to it possessed by the crosses 112, 117, 122, 130, and 131.

McDonald [5] found that the Kenya races K. 1, K. 2, K. 3, and K. 4 were likely to be identical with the American races 21, 17, and 34 and the Canadian race 116, but no similar identifications of the more recent K races have been made.

Production of New Hybrids, 1921–30

Burton, after sifting out the material—much of it unfixed and unnamed—inherited from his predecessors, made a large series of crosses from which resulted what may be called the early Kabete and Njoro hybrids (named after the places at 5,700 and 7,100 ft. alt., at which he

worked). The parents used in these crosses were mostly unknown hybrids or varieties, but one named variety, Red Egyptian, proved valuable because it resisted stem rust at that time.

The wheats then grown in the Colony were mainly Equator, Golden Ball, and mixtures from Crosses XI and XIII. Equator, a selection made by Evans out of a field of wheat grown at Njoro, became established at the higher levels because it resisted yellow rust. A further selection from the inherited material by Burton was released as 'Kenya Governor' in 1925. Having early maturity and resistance to stem rust at that time, it was largely grown at the lower altitudes, where it matured in 4 months.

Many varieties were imported for trial, but all proved unsuitable either because they were susceptible to stem rust or they were too slow in maturing. The one exception was the South American, Sabanero, imported in 1927.

The main function of the Kabete station was to produce early-maturing stem-rust-resistant wheats for areas under 7,000 ft. having two rainy seasons, short days, and a 4-month growing season. In 1930 several thousand bags of one of these early Kabete hybrids, Kenya Standard, which had shown resistance to stem rust and was early maturing were sown. For various reasons, and chiefly owing to its marked susceptibility to leaf rust under field conditions, this wheat was not carried on, although in 1930 it was the only variety being grown on any scale which was resistant to the two known races of stem rust (K. 1 and K. 2). Kenya Governor, which was largely grown at the same time, had been found susceptible to race K. 1 though resistant to race K. 2. This variety is still grown at the present time owing to its early maturity, though it periodically suffers some rust damage.

At Njoro wheats were bred for resistance to stem and yellow rust for the higher areas of 7,000 ft. and where one prolonged rainy season is normal. Very early maturity was not required here, a period of 5–6 months being suitable. Breeding with Rieti proved difficult because its ear-grain quality is not readily separable from its resistance to stem rust.

1931–40.—By this time two further races of stem rust had been isolated and whilst Kenya Standard was resistant to the first of these races, K. 3, it, like other matured hybrids found in it and used as found, proved susceptible to the second race, K. 4.

The best of the strains from these crosses were, however, issued to farmers on a large scale in 1935 in the hope that race K. 4 would not prove to be a serious menace. This expectation was shortlived as in the same year race K. 4 became epidemic over the whole country and all these wheats proved highly susceptible.

Two further wheats of medium early maturity which had been bred at Kabete were also under trial by farmers at this time. One, B. 256. G., which was suited to the medium altitudes proved to be susceptible to races K. 4 and K. 5 and is grown now only on a small scale. The second wheat, NB. 230. A. 14 (L), a selection from the cross Bobs × Rieti was susceptible, like Kenya Governor, to a number of races of stem rust but resistant to yellow rust at the higher altitudes. It has therefore been grown in the higher areas to some extent, as apart from its resis-

tance to yellow rust and to race K. 2 of stem rust which is generally present at these heights, its medium early maturity, as against the late maturity of Equator, has proved useful when a short-term wheat was required.

At Njoro the position of races K. 3 and K. 4 was more satisfactory since the early Njoro hybrids proved to be resistant to both. Accordingly, it was expected that subsequent crosses which had been made, utilizing these wheats as the stem-rust-resistant parents, would still prove of value. Pure-line strains were obtained and bulked from the following crosses:

Cross 112—K. 2. R. 5. (L. 2) × English hybrid from Engledow. (Njoro hybrid)
„ 117—A. 8. V. 12. D. (L) × Marquis. (Njoro hybrid)
„ 122—A. 8. E. 7. E. (L. 3) × Marquis. (Njoro hybrid)
„ 130—K. 2. R. 5. (L. 2) × Selection out of Australian Florence. (Njoro hybrid)
„ 131—A. 8. D. 28. B. (L. 1) × Selection out of Australian Florence. (Njoro hybrid)

Cross No. 112.—The origin of Engledow's hybrid is not known as the seed became mixed with other hybrids in transit, but it is possible that Yeoman was one parent. Several strains from this cross were selected and issued to farmers under the serial numbers 500, 501, &c., and 6,000 bags of seed were sown in 1936. These wheats were suited to altitudes of 7,000 ft. upwards, two of them possessing sufficient yellow-rust-resistance to allow of their being grown up to 8,500 ft. Resistance to races K. 1, K. 3, and K. 4 of stem rust was obtained but not to race K. 2, a failure that must be attributed to the Njoro hybrid parents not possessing sufficient resistance to this form. These strains from cross 112 yielded reasonably well and proved valuable to the country at a time when K. 4 was epidemic in the Colony.

Crosses Nos. 117 and 122.—These two crosses (Njoro hybrid × Marquis) produced some useful material and several strains were increased and grown on a small scale, but with one exception they also all proved susceptible to race K. 2. This exception was a strain in cross 117, which has since become the predominant wheat in the Colony owing to its rust-resistance. This wheat, No. 117. A, has in fact shown resistance to each new physiologic race of stem rust as it has appeared. No. 117. A. is a medium maturing wheat of good yielding capacity, tall but weak straw, moderate baking quality, susceptibility to leaf rust, and to yellow rust at the higher altitudes over 8,000 ft. In 1938, 2,000 bags of seed were harvested and since then an ample supply of seed has been available.

Other strains of crosses 117 and 122 that have shown susceptibility in the field in Kenya have proved highly resistant under Canadian conditions, and this high resistance has broken down only when tested in the seedling stage at very high temperatures. One of these strains, 117. I. 5. F. (L), was grown by several farmers for some years; it rusted badly periodically and both it and another strain, 122. D. 1. T. (L), have regularly shown susceptibility in the breeding-cages.

Crosses Nos. 130 and 131.—The selection out of Australian Florence was chosen for its resistance to yellow rust in particular. The strains built up and issued were not resistant to race K. 2, though resistant to the other three races of stem rust and to yellow rust; eventually they had all to be discarded owing to susceptibility to K. 2.

Cross No. 58.—This cross (Red Egyptian × Unknown inherited hybrid out of Dowson's material) was originally started at Kabete and subsequently transferred to Njoro as being too slow maturing for the former station. One selection showing resistance to races K. 1, K. 2, K. 3, and K. 4 of stem rust was finally increased and 10,000 acres were sown to it in 1937. In 1936 a slight infection of stem rust had been found on this wheat and in the following year rust was general on the crop. Investigation showed that this rust was a further new race, K. 5. No. 58 has subsequently shown resistance to races K. 6 and K. 7 and is therefore susceptible only to race K. 5. Growers, however, have not forgotten the epidemic of K. 5 in 1937, since when this wheat has not been grown on any scale, and there is every probability that if No. 58 was once more largely grown, race K. 5, which has been present in the country of recent years, would again assume epidemic form and destroy it.

More recent crosses.—With the arrival of race K. 5 of stem rust in 1937 and of race K. 6 in 1940 it became necessary for the writer to review the hybrid material then being grown [7]. In some of the crosses it was found that both parents were susceptible to one or both of these new races, which meant discarding any such cross. Much material, hitherto considered of promise, had to be culled for this reason. The American wheat Reliance, in view of its resistance to race K. 5 (Reliance is resistant to all the first five races except K. 3) had been used in a number of crosses. The arrival of race K. 6, to which Reliance was susceptible, meant abandoning any crosses in which both parents showed susceptibility to K. 6. Further series of crosses have therefore had to be made. The presence of still another new race, K. 7, in 1943 has not simplified matters, though fortunately many of the pure-line wheats are proving resistant rather than susceptible to this last race. Of the newer crosses, from which pure lines have been obtained and are now under multiplication, the following may be mentioned as of importance:

Cross No. 291 (Australian 26. A × 58. F. (L.1)).—Wheat No. 58, which was put out of action by the arrival of race K. 5, is in fact susceptible only to this race, whilst Australian 26. A. is resistant to it. One strain, No. 291. J. 1. I. 1, bred from this cross has been shown by seedling inoculations to be resistant to all seven races and to date has also shown complete resistance in the field; 1,000 bags of seed of this strain were available for sowing in 1945. This wheat is promising, though it has yet to be fully proven; it has good straw, is of medium early maturity, and suited to the medium altitudes up to 7,000 ft., where it has yielded well. It is, however, susceptible to leaf rust and its baking quality is not good.

Cross No. 294 (Australian 26. A × 117. A).—Several rust-resistant strains have been increased and issued to growers for further trial and multiplication. They vary from early to medium maturity, possess very

fair straw, and have yielded better than the standard varieties in yield trials. They are likely to be suitable to altitudes up to 8,000 ft. and possess very fair baking quality.

Cross No. 261 (*Kabete hybrid* × *Reliance*). One or two early-maturing strains are in the hands of growers, although they show a slight susceptibility to race K. 7. The quality of the grain is good and they are in particular suited to the lower areas, which require quick-maturing wheats.

One further wheat, a Kabete hybrid No. 192. Q. 2. A. (L), of unknown origin has consistently shown resistance to stem rust in the field, and in view of its earliness, it was increased, 300 bags being harvested in 1941. It is very susceptible to leaf rust, and the appearance of the grain is generally unattractive though it can produce grain of good quality. It has, however, been of some value in the lower areas where earliness and stem-rust-resistance are essential.

In the latest crosses use has been made of the Australian variety Warigo. Seedling tests show this wheat to be resistant to 4 of the 7 K races of stem rust only, and it has not shown complete resistance in the field. In Australia it possesses high mature-plant resistance to stem rust, and as it is resistant to leaf rust and a number of other diseases, it has been crossed with some of the newer Kenya hybrids that have shown resistance to stem rust both in the seedling stage and in the field.

Selections and Introduced Varieties

Sabanero.—This variety, a sample of which was received by the Kenya Farmers' Association Ltd., from Colombia, South America, in 1927, was grown by a farmer Mr. Theunissen on the Elgeyo Border. It was subsequently increased and is now one of the main varieties grown. In the field it has shown fair resistance to stem rust, though seedling inoculations show it to possess some susceptibility to the last two races, K. 6 and K. 7. It is resistant to yellow rust up to 8,000–8,500 ft. and susceptible to leaf rust. It is a little earlier maturing than No. 117. A, yields somewhat less, and like No. 117. A, lacks strength of straw. These two wheats, owing largely to their rust-resistance, now account for more than half the Colony's wheat acreage, wartime conditions demanding as much wheat as possible, irrespective of bread-making quality. The baking quality of Sabanero is not, unfortunately, good, the gluten being characterized by a tendency to excessive distensibility, and whilst this wheat can be blended with more stable varieties the mills prefer not to use more than 20 per cent. of it in their blends.

Simpson's wheats.—In 1935, a farmer, Mr. H. Simpson of Rongai, grew a crop of Kenya Standard which was badly rusted by race K. 4 of stem rust. In the crop he found some natural hybrids which were free of rust. Selections were made out of this material and two strains known as Simpson's Rongai and Simpson's L. 3 were increased and issued in 1939. These two wheats also possessed some tolerance to some of the other races of stem rust and proved of value where a quick-maturing wheat was required, though damage by stem rust, in some

cases involving complete loss of crop, has been reported. They are not heavy-yielding wheats but their baking quality is well above the country's average.

Reward.—This Canadian variety has been grown for some years in a few areas where it often escapes rust. It is noteworthy for the very high-quality grain it can produce, but it cannot be recommended because it is susceptible to all races of stem rust.

Double Cross × *Ceres 721* is another Canadian production which has shown some, but by no means complete, resistance to stem rust. It has been grown on a limited scale for some years and is suited to the medium altitudes. Two rust-free strains in it were selected in 1937 as were several further strains subsequently. These selections have to date maintained this resistance and are under trial on a small scale, but neither they nor the original strain appear to suit all conditions.

Australian 26. A.—This Australian–Kenya hybrid (Kenya Standard × Baringa × Nabawa × Wandilla) bred in N.S. Wales showed resistance in the field to race K. 5 when this race first appeared and was accordingly increased. Owing, however, to its susceptibility to most of the other races it has subsequently been discarded. In other respects it promised very well and has been used as a parent in a number of crosses. Most Australian wheats are agronomically very suited to this country.

Golden Ball is a durum wheat which has been grown in the country for many years on a limited scale. Originally it was thought to possess some stem-rust-resistance, but it has failed to maintain this resistance; it is now grown because it is the only durum variety available to the mills for the atta trade. Some durum varieties have been imported for trial but all have proved to be susceptible to stem rust under Kenya conditions.

Reliance.—This American variety was increased in 1930 because it had served as a differential in seedling inoculation tests, and had shown resistance to races K. 1 and K. 2 of stem rust. In that season, however, it rusted in the field (race K. 3). Subsequently it proved resistant to races K. 4 and K. 5 and was again increased and issued to growers as a temporary measure, only to show itself susceptible to races K. 6 and K. 7 when they appeared.

Australian Florence was imported in 1925 (?) and was grown for a time on a small scale at the high altitudes, where it showed some resistance to yellow rust, but not to stem rust.

Burbank or Burbank's Quality has been grown on a small scale for some years in one or two areas. It possesses good straw, good baking quality, and early maturity, but is very susceptible to stem rust.

Regent.—This Canadian variety, grown on a small scale for several years, has stood and yielded well. It has, however, not shown complete resistance to stem rust and is therefore still under trial. It is resistant to leaf rust, and to yellow rust at the higher, but not the top altitudes.

REFERENCES

1. W. J. Dowson, Wheat in East Africa. Dept. Agric. Nairobi, B.E.A., 1919, Bull. No. 4.
2. G. J. L. Burton, Wheat Growing in Kenya Colony. Kenya Dept. Agric. 1925, Bull. No. 2; 1929, Wheat Breeding in Kenya, Bull. No. 7D.
3. D. W. Kent Jones, Modern Cereal Chemistry. The Northern Publishing Co., Ltd., Liverpool.
4. E. C. Stakman and M. N. Levine, The Determination of Biologic Forms of *Puccinia graminis* on *Triticum* spp. Minn. Agric. Expt. Stat., 1922, Tech. Bull. No. 8.
5. J. McDonald, Investigations on Stem Rust of Wheat in Kenya Colony. Kenya Dept. Agric., 1931, Bull. No. 1.
6. C. H. Goulden, K. W. Neatby, and J. N. Welsh, The Inheritance of Resistance to *Puccinia graminis tritici* in a Cross between two Varieties of *Triticum vulgare*. Phytopath., 1928, 631–58.
7. R. J. Lathbury, The Appearance of a new Physiologic Form of Stem Rust in Kenya Colony. E. Afr. Agric. Journ., 1938, **4** (3).
8. Margaret Newton, T. Johnson, and B. Peterson, Seedling Reactions of Wheat Varieties to Stem Rust and Leaf Rust and of Oat Varieties to Stem Rust and Crown Rust. Canad. J. Res., 1940, C, **18,** 489–506.

(*Received February 11, 1947*)

APPENDIX A

ACREAGE AND PRODUCTION OF WHEAT IN KENYA COLONY

Year	*Acres harvested*	*Bushels per acre*	*Year*	*Acres harvested*	*Bushels per acre*
1919	5,614	6·0	1932	30,114	7·0
1920	4,999	8·7	1933	35,001	13·7
1921	10,593	9·0	1934	43,505	13·7
1922	15,158	8·0	1935	52,135	9·7
1923	19,599	9·3	1936	57,410	9·0
1924	23,996	9·0	1937	57,174	10·7
1925	30,627	8·7	1938	44,251	14·3
1926	46,601	8·3	*War years*		
1927	75,102	7·7	1941	103,000	7·7
1928	82,951	9·0	1942	122,322	11·3
1929	63,217	15·3	1943	139,905	16·7
1930	68,815	9·3	1944	160,171	12·3
1931	43,168	6·7	1945 (Est.)	184,583	15·3

MOLO/MAU DISTRICT

Average yields (bu. per acre): 1919–28, 8·4; 1929–38, 10·9; 1919–38, 9·5; 1941–5, 12·7

Year	*Acres harvested*	*Bushels per acre*	*Year*	*Acres harvested*	*Bushels per acre*
1942	7,007	21·7	1945 (Est.)	10,212	20·0
1943	6,992	29·0			
1944	8,378	23·3	1942–5	..	23·5

APPENDIX B

List of hybrid varieties produced by the Department of Agriculture showing the year in which they first became available in quantity, i.e. several thousand bags of seed:

Year	*Variety*	*Year*	*Variety*
1920	Equator	1937	58. F. (L. 1)
1926	Kenya Governor	1939	117. A
1930	Kenya Standard	1939	Crosses 130 and 131
1933	NB. 230. A. 14. (L)	1946	291
1936	Cross 112—Strains Nos. 500, 501, &c.		

Imported varieties increased and grown on a large scale:

1934	Sabanero	1939	DC × Ceres 721 (moderate scale only)

A COMPARISON OF INORGANIC FERTILIZERS AND COMPOST ON NATURAL PASTURES IN SOUTH AFRICA

D. MEREDITH

(Senior Agronomist, Agricultural Advisory Section, African Explosives and Chemical Industries, Ltd., Johannesburg, U.O.S.A.)

In view of the widespread claims made in the popular press on behalf of compost applications for all crops, and also in many instances for pastures, it was considered advisable to investigate the effect of compost dressings on natural veld. This paper describes the experiments conducted at the Frankenwald Botanical Research Station of the University of the Witwatersrand. The natural veld type and the climate of this area and soil type of the station have been described in previous papers by Weinmann [1] and Hall *et al.* [2]. In a previous experiment Hall *et al.* [3] found that the nitrogen in inorganic fertilizers was used more efficiently by a Digitaria species in a planted pasture than that contained in compost. The percentage recoveries of nitrogen over two seasons were 10·4 and 22·9 for heavy and light dressings of compost respectively, and 27·9 and 45·0 for heavy and light fertilizer applications.

Experimental

The experiment was put down on a camp which had previously been used in a grazing experiment but had not been fertilized since work on this station was started in the 1932–3 season. Some years previously a portion had been ploughed and cropped but had been allowed to go back to grass. When this experiment was put down it was thought that the ploughed area had been under grass for at least 20 years.

Fifteen plots were put down on each veld type, which, for the sake of convenience, may be referred to as undisturbed (or natural) veld and disturbed veld (old fallow).

Three randomized plots, each of 1/82·6 morgen[1] were used for the following five treatments on each veld type:

A. Compost, 20 tons per morgen.
B. Fertilizer treatment as nearly equivalent as possible in N, P_2O_5, K_2O, and CaO contents to A. (See Table 1.)
C. Standard fertilizer dressing per morgen, namely, 400 lb. rock and superphosphate, 400 lb. sulphate of ammonia in two dressings, and 80 lb. chloride of potash per morgen each season.
D. Compost dressing equivalent as far as possible in plant-food content to treatment C.
E. Control: no treatment with fertilizer or compost.

Originally it was proposed to apply all treatments annually, but, when the compost was analysed, is was found that the equivalent nitrogen dressing in the B treatment was so high, that it was thought unwise to apply it all in one season. It was decided, therefore, to apply the A and

[1] Morgen = 2·116 acres or 10,244 sq. yds.

B treatments over two seasons and compare all treatments on a basis of two-year cycles. Yields and applications are presented on this basis.

Veld types.—Before any treatments were applied three one-quarter square-metre quadrats were analysed in each plot by the basal cover method at ground-level. The results showed that the vegetative cover was poor, there being 81·3 per cent. bare ground in the undisturbed veld and 85 per cent. in the disturbed type.

In the undisturbed veld type there was on the average 1·78 per cent. *Tristachya hispida*, 6·4 per cent. *Digitaria tricholaenoides*, 2·4 per cent. Eragrostis species, and 8·1 per cent. of other less important grasses and veld plants. The plant-cover in the disturbed veld, on the other hand, consisted of 1 per cent. *Heteropogon contortus*, 2·4 per cent. *Cynodon dactylon*, 1·6 per cent. *Eragrostis chalcantha*, 7·0 per cent. other Eragrostis species, and 2·9 per cent. other grasses and veld plants.

It is proposed to analyse these veld types again after the experiments have been in progress for 10 years.

Applications of compost and fertilizer.—The botanical survey was completed early in January 1943, and the compost dressings were applied to some of the plots on December 28, 1942. The compost used had the following percentage composition:

Moisture	41·9	P_2O_5	0·3
Organic and volatile matter	21·0	K_2O	0·8
Ash	37·1	CaO	0·9
Nitrogen	0·8		

The compost used subsequently had a similar composition. Table 1 shows the amounts of plant-food applied in the two cycles.

TABLE I. *Fertilizer Constituents applied in Veld Experiment, Frankenwald (pounds per morgen)*

Treatment	First cycle				Second cycle			
	N	P_2O_5	K_2O	CaO	N	P_2O_5	K_2O	CaO*
A. High compost	320	120	320	360	380	124	128	372
B. Equivalent fertilizers	326	121	321	..	380	171	320	..
C. Standard fertilizer	129	136	96	..	166	96	48	..
D. Low compost	171	65	174	196	171	50	40	152
E. Control	..	..	..	..	..	..	..	..

* Assuming 0·9 per cent. CaO as in 1942.

The compost and fertilizers were spread evenly by hand on the surface of the respective plots, and no cultivation was undertaken at any time to incorporate these applications in the soil.

Methods of Harvesting.—The plots were not large enough to be grazed, but were of such a size that the herbage, if air-dried, could be weighed on a large counter-scale. The procedure adopted was to mow one or both sections of the plots with an ordinary ox-drawn mower, after the pathways between plots had been mown with a lawn mower. The grass was then left on the sward until it was dry, which usually took one or two days; it was then raked by hand, put into clean bags, and weighed. After weighing, the herbage from each plot was sampled for chemical

analysis and the samples bulked for each treatment. Towards the end of the period under review a small two-wheeled tractor mower was used to mow the plots in place of the ox-drawn implement.

TABLE 2. *Dry-matter Yields on Veld (Frankenwald) (pounds of dry matter per morgen)*

	First cycle					*Second cycle*							
Treatment	*Apr. 1943*	*Nov. 1943*	*Jan. 1944*	*Mar. 1944*	*Total*	*Nov. 1944*	*Dec. 1944*	*Feb. 1945*	*May 1945*	*Jan. 1946*	*Feb. 1946*	*Apr. 1946*	*Total*
Undisturbed veld													
A	284	477	1,137	919	2,817	469	709	354	672	586	1,350	878	5,018
B	387	502	2,078	1,941	4,908	728	870	616	992	819	3,455	1,570	9,050
C	220	288	975	1,297	2,780	411	469	394	623	587	1,931	974	5,389
D	214	466	1,010	943	2,633	525	437	342	619	601	1,367	955	4,846
E	111	261	557	527	1,456	348	304	221	281	503	882	559	3,098
Disturbed veld													
A	124	357	621	878	1,980	588	666	446	537	661	1,512	768	5,178
B	1,249	869	2,264	3,316	7,698	854	901	571	1,122	760	5,004	1,274	10,486
C	391	358	951	1,556	3,256	531	521	408	599	672	2,640	957	6,328
D	243	329	615	763	1,950	410	375	423	594	638	1,320	659	4,428
E	122	204	357	501	1,184	305	155	253	314	413	786	461	2,687

Rainfall (inches): 1942–3, 33·29; 1943–4, 37·34; 1944–5, 28·97; 1945–6, 24·94.

Statistical Analysis of Results

TABLE 3. *Yields in Pounds of Dry Matter per Morgen*

Fertilizer treatment	*Undisturbed*		*Disturbed*	
	lb.	%	*lb.*	%
A	3,918	90	3,579	82
B	6,978	160	9,092	209
C	4,085	94	4,792	110
D	3,739	86	3,189	73
E	2,277	52	1,936	44
Mean	4,199	96	4,517	104

	Fertilizer treatments	
	Means	*Interactions*
Variance ratio (V)	75·7	4·8
V-requirement ($P = 0·05$)	2·61	2·61

After the first application of compost (Dec. 1942) the herbage was first cut in April 1943; thereafter the plots were mown in November 1943 and January and March 1944. In the 1944–6 cycle the first dressings were given in October and November 1944; the plots were mown seven times, starting in November 1944 and ending on April 30, 1946.

The yields of dry matter obtained are shown in Table 2 as averages of three plots in each section.

It is noteworthy that although the disturbance of the veld as a primary factor did not greatly increase herbage yields, the interaction between disturbance and fertilizer treatment was highly significant: no doubt mainly because B had such a high reaction on the disturbed veld.

The interaction between cycles (seasons) and fertilizer treatments is significant. This must be ascribed principally to the differential improve-

ment in the second cycle (E has improved almost threefold, A, C, and D about twofold, and B approximately one and a half times).

Treatment B has given the largest response by far, followed by treatment C, which is in turn significantly better than A. D is better than the control and not significantly inferior to A. In both cases the inorganic dressings have outyielded their organic equivalents.

It is interesting to note that the high manurial value of treatment B finds its highest response with a disturbance of the veld, but in the cases of treatments A, D, and E such disturbance seems to have lowered the efficiency of the treatments.

The samples from the four cuttings of the first cycle were analysed for N, P_2O_5, K_2O, and CaO at the Umbogintwini Factory; in the second cycle only the moisture- and nitrogen-contents of the samples were determined.

Table 4 shows the application of nitrogen and the recovery of nitrogen in the two cycles.

The recovery of P_2O_5 in the first cycle is shown in Table 5.

Discussion

Although no botanical survey has been made since the original one, certain obvious changes have taken place, e.g. in the undisturbed veld the cover has increased in density. Weeds and herbs have not increased to any marked extent, except in a few small bare areas.

The most noticeable changes have taken place in the disturbed veld area, where in the first season *Hyparrhenia hirta* gave a marked response to all treatments, but in particular to the heavy fertilizer-treatment. Later, on the heavily fertilized plots, a fine-leaved species of Eragrostis—probably *E. nebulosa*—ousted most of the Hyparrhenia. Species characteristic of the undisturbed veld also appear to be spreading, notably *Trachypogon plumosus*.

The average dry-matter yields given in Table 2 show that inorganic fertilizers have given twice the yields given by the compost treatments. Further, the yields on the disturbed veld are slightly higher than on the undisturbed type. In the first cycle this was due to the coarse growth of *Hyparrhenia hirta*, but in the second cycle to the dense growth of the Eragrostis species.

Table 4 shows that the highest percentage recoveries of nitrogen have been given by the treatments receiving nitrogen in the inorganic form, and that these recoveries have been greater on the disturbed veld type than on the undisturbed type.

The yields of dry matter per pound of nitrogen applied afford further evidence of the greater efficiency of inorganic nitrogen in both types of sward. It is also noteworthy that in both cycles the returns of nitrogen and also yields of dry matter per pound of nitrogen have been higher for the low compost-dressing than for the high dressing. This seems to indicate a high rate of loss of nitrogen from liberal dressings of compost on pastures, and suggests that if compost is to be used on veld pastures it should be applied frequently in small amounts.

Table 5 shows that in general phosphate recoveries are low, but nevertheless, the high fertilizer-treatment has given the best return.

TABLE 4. *Recovery of Nitrogen*

Treatment	*N applied (lb./morgen)*	*N % of herbage*	*Total N in herbage (lb./morgen)*	*N-uptake (lb./morgen)*	*Return of N %*	*Lb. dry matter per lb. of N applied*
FIRST CYCLE—*Undisturbed veld*						
A	320	1·18	30	17	5·3	4·2
B	326	1·29	55	42	12·8	10·5
C	129	1·27	31	18	14·0	10·2
D	171	1·04	26	13	7·6	6·8
E	..	1·08	13	..	..	..
Disturbed veld						
A	320	1·22	23	11	3·4	2·5
B	326	1·33	101	89	27·3	19·9
C	129	1·13	36	24	18·6	16·0
D	171	1·04	20	8	4·6	4·4
E	..	1·04	12	..	..	..
SECOND CYCLE—*Undisturbed veld*						
A	380	1·08	55	22	5·7	5·0
B	380	1·26	120	87	22·8	15·6
C	166	1·12	62	29	17·4	13·8
D	171	1·06	52	19	11·1	10·2
E	..	1·00	33	..	..	..
Disturbed veld						
A	380	1·08	58	31	8·1	6·5
B	380	1·18	132	105	27·6	20·5
C	166	1·08	73	46	27·7	21·9
D	171	1·04	49	22	12·8	10·2
E	..	0·96	27	..	..	..

TABLE 5. *Recovery of P_2O_5 in First Cycle*

Treatment	*P_2O_5 applied (lb./morgen)*	*P_2O_5 % of herbage*	*Total P_2O_5 in herbage (lb./morgen)*	*P_2O_5 uptake (lb./morgen)*	*Return of P_2O_5 %*
Undisturbed veld					
A	120	0·25	7	4	3·3
B	121	0·27	14	11	9·1
C	136	0·26	8	5	3·6
D	65	0·23	6	3	4·6
E	..	0·20	3	..	..
Disturbed veld					
A	120	0·28	6	3	2·5
B	121	0·27	20	17	14·0
C	136	0·24	10	7	5·1
D	65	0·24	5	2	3·1
E	..	0·22	3	..	..

Applications of phosphate in either the organic or inorganic form have not increased the P_2O_5-content of the herbage to any great extent, although in other experiments [2] the application of phosphatic fertilizers has practically doubled the P_2O_5-content.

In general, the yields of dry matter per unit area are low. The highest yield recorded, namely, 10,486 lb. per morgen for the B treatment in the second cycle, represents a yield of about 2,500 lb. per acre per annum. As the sulphate-of-ammonia treatment worked out at about 375 lb. per acre per annum, it is possible that higher applications might give greater returns. It will also be noted that the average nitrogen-content of the herbage was low, and thus far in this experiment the crude protein-content of the air-dry herbage has not exceeded 8 per cent. This seems characteristic of the herbage from this veld type, and improvement will possibly be effected only by increasing the nitrogen applications or by encouraging clovers and other legumes in the sward. There is little prospect of the latter alternative being successful in the near future.

Summary.—Compost and fertilizers were applied on two veld types at two levels over two 2-year cycles, and yields of dry matter were obtained from four cuts in the first cycle and seven in the second.

The yields of dry matter showed a greater response to nitrogen in the inorganic than the organic form. In both cycles the response was greater on a disturbed or old fallow veld type than on the undisturbed veld.

Recoveries of nitrogen ranged from 3·4 to 12·8 per cent. in the compost-treatments and from 12·8 to 27·7 per cent. in the fertilizer-treatments. The yield of dry matter per pound of nitrogen applied ranged from 2·5 lb. in a heavy compost-treatment to 21·9 lb. in one of the fertilizer-treatments.

In general, the application of phosphate in either the organic or inorganic form did not have much effect on the phosphate-content of the herbage, and phosphate recoveries were, for the most part, low.

The recoveries of nitrogen and the yields of dry matter per pound of nitrogen were higher for the lower compost-dressings than for the heavy dressing. From this it is concluded that if compost is to be applied to pastures it should be applied frequently in fairly light dressings.

Acknowledgements.—The writer wishes to thank Dr. T. D. Hall, Agricultural Adviser to African Explosives and Chemical Industries Limited, for having suggested these investigations and for help in planning the experiments. Thanks are also due to Prof. John Phillips and members of the Botany Department of the University of the Witwatersrand, and in particular to Mr. R. Rose-Innes for assistance rendered during the preliminary botanical survey; to Mr. A. R. Hughes for help in calculating yields and recoveries of nitrogen and phosphate; and also to Mr. F. X. Laubscher, of the Potchefstroom College of Agriculture, for valuable assistance with the statistical analysis.

REFERENCES

1. H. WEINMANN, Effects of Defoliation Intensity and Fertilizer Treatment on Transvaal Highveld. Empire J. Expt. Agric., 1943, **11**, 113–24.
2. T. D. HALL, D. MEREDITH, and S. M. MURRAY, Fertilizing Natural Veld and its Effect on Sward, Chemical Composition, Carrying Capacity and Beef Production. S. Afr. J. Sci., 1940, **37**, 111–29.
3. —— A Comparison of Compost and Inorganic Fertilizers as Top Dressing for Established Pasture. Ibid., 1942, **39**, 116–25.

(*Received December 3, 1946*)

EXPERIMENTS WITH POTATOES IN CYPRUS

L. J. S. LITTLEJOHN

(*Botanist and Plant Pathologist, Department of Agriculture, Cyprus*)

Introduction.—In Cyprus two main crops of potatoes are grown in the plains districts (up to 750 ft.); the first crop is planted in February and lifted mainly in June; the second is planted in August and matures about the end of November. In the hill districts (1,500–4,000 ft.) a minor crop is planted in April and harvested in August or September. All potatoes are grown under irrigation.

Before the war rather less than half of the first main crop was planted with imported Irish seed, the variety Up-to-Date being used exclusively. The second main crop was planted with 'once-grown' seed. The average commercial potato-grower planting Irish or 'once-grown' seed expects a yield of at least 90 cwt. per acre. Yields of more than 200 cwt. per acre have been recorded fairly often. Two such crops can be obtained in one year though not normally from the same land.

The acknowledged superiority of imported Irish seed as compared with normal Cyprus-grown seed appears to be due to two main causes. First, seed which has been grown for several generations in Cyprus becomes heavily infected with various viruses from which imported certified seed is comparatively free. Secondly, locally produced seed lifted in November is still in a dormant state in February and when planted in this condition fails to germinate or germinates very irregularly. Owing to war conditions no seed was imported into Cyprus in the years 1941, 1942, and 1943, and the supply in 1944 and 1945 was irregular. Table No. 1 shows how the average yield of potatoes fell as the 'age' of the seed increased. The figures given are probably not absolutely accurate, being based on farmers' annual returns and agricultural officers' estimates, but taken relatively they indicate the general trend towards lower yields from 1941 to 1943 with partial recovery in 1944 and 1945 following the importation of some United Kingdom seed.

TABLE 1. *Average Yield for Each Potato Crop* (*cwt. per acre*) *1939–45*

Year	*First main crop Feb.–June*	*Second main crop Aug.–Nov.*	*Remarks*
1939	76·5	93·5	
1940	68·0	75·0	
1941	45·5	64·5	Shortage of fertilizer for first crop
1942	64·0	51·0	
1943	52·5	40·0	
1944	63·0	70·0	1,300 t. seed imported, mostly Arran Banner
1945	70·0	79·0	350 t. Up-to-Date and Arran Banner imported

Since 1938 experiments have been made with four main objects in view:

(*a*) Variety trials have been carried out with a view to finding a variety as good as, or better than, Up-to-Date which, owing to its susceptibility to blight, is going out of favour in the U.K., so that seed is becoming increasingly difficult to obtain.

(*b*) The use of 'rose-ends' and 'cut-eyes' as a means of economizing in planting material was investigated.

(*c*) Various methods that might be suitable for use by the local farmer for breaking the dormancy of autumn-lifted potatoes have been tried.

(*d*) A seed-certification scheme for local seed has been started, and various trials with locally certified seed have been made.

Experimental

All trials have been laid out on statistical lines. The significant difference shown in the tables or mentioned in the text is taken at the level $P = 0{\cdot}05$. Most of the trials have been carried out at the Central Experimental Farm of the Department of Agriculture, which is situated on a rather poor alluvial soil. Local experience has shown that this soil is not very suitable for potatoes, which appear to thrive best on typical *terra rossa* soils, and some trials have been made on these. In many cases two or more of the main objects mentioned above were combined in one experiment, but for convenience in discussion the results are separated into the four main headings.

(*a*) *Variety trials.*—Before 1938 the following varieties were imported for trial by the Department of Agriculture: Irish Cobbler, Green Mountain, Bliss Triumph (all from Canada); King Edward, Sharpe's Express, Snowdrop, May Queen, Ulster Monarch, Dunbar Standard, Arran Cairn, Arran Victory, Arran Signet, Arran Peak (from the U.K.). No records are available as to the fate of these varieties but presumably none showed any signs of outyielding Up-to-Date. Table 2 shows the

TABLE 2. *Results of Potato Yield Trials* (*cwt. per acre*)

	Year, soil, and crop**										
Variety	*1939 R.I*	*1939 A.I*	*1939 R.II*	*1939 A.II*	*1940 A.I*	*1943 A.I*	*1944 A.I*	*1945 R.I*	*1945 A.I*	*1945 A.I*	*1945 R.II*
Up-to-Date	135·9	40·5	83·0	104·0	89·0	60·9	87·2	194·0	128·0	141	126
Arran Banner	128·6	42·5	66·4	97·0	63·5	..	70·0	208·0	112·0	129	93
Majestic	132·6	45·5	75·0	111·2	..	..	..	..	..	..	..
Arran Peak	30·1	19·8	80·3	73·3	..	..	..	..	..	..	..
Dunbar Standard	51·9	4·2	81·9	84·4	..	..	..	51·0	58·5	59	86
Craigs Defiance	..	..	..	..	..	..	..	217·0	103·0	104	77
Gladstone	..	..	..	..	..	..	66·2	..	..	..	..
Royal Kidney	..	..	..	..	11·8	..	..	..	..	..	..
King Edward	..	..	..	..	15·1	..	..	..	..	..	..
Epicure	..	..	..	..	..	45·3	..	..	..	..	..
Sharpe's Express	..	..	..	..	..	2·4	..	..	..	..	..
Eclipse	..	..	..	..	..	5·8	..	..	..	..	..
Arran Pilot	..	..	..	..	..	16·1	..	..	..	..	..
Baron	..	..	..	..	..	15·7	..	..	..	..	..
Archangelos	..	..	..	..	..	37·8	..	..	..	..	..
Sign. diff.	29	7·1	9·2	8·0	11·25	13·26	11·25	8·0	10·9	12·4	14·2

* R = *Terra rossa.* A = Alluvium. I = First main crop. II = Second main crop.

results of all variety trials carried out since 1938; the seed used throughout was certified U.K. seed for the first main crop and 'once-grown' seed for the second crop.

Although occasionally outyielded by some varieties, Up-to-Date is the most consistent high yielder. Majestic, which gave consistently high yields, always developed a serious fault in that the tubers cracked badly and tended to deteriorate very rapidly in storage. Arran Banner is a fairly consistent yielder, and considerable quantities have been grown in recent years when the supply of Up-to-Date seed was insufficient for shipment to Cyprus. Experience has shown that it does reasonably well for the first main crop, but for the second and subsequent crops it falls a long way behind Up-to-Date. Local farmers also aver that it requires more water than Up-to-Date. It appears, moreover, that some U.K. Arran Banner seed gives rise to crops in which a very high percentage of the tubers are affected with 'sprain'. This disease first appeared in 1944 and 1945 and only on crops grown from newly imported seed. The disease did not appear at all on the second crop even though in some cases infected seed was used for planting. No specific organism could be isolated from infected tubers, nor could the symptoms be carried from an infected tuber to a clean tuber by keeping them in close contact. To sum up, no satisfactory substitute for Up-to-Date has so far been found for use in Cyprus.

A curious feature of the varietal behaviour in Cyprus is that there seems to be little difference in the time required to reach maturity between varieties regarded in the U.K. as earlies, such as Epicure and Arran Pilot, and late or main crop varieties such as Up-to-Date and Arran Banner. In Cyprus the maturity period for all varieties when grown in the plains appears to be about 120 days as compared with 160 days required to mature main crop varieties in the U.K., and the only difference is that earlies have invariably given a very poor yield as compared with main-crop varieties. The difference in maturity-period of potatoes grown in various countries has been commented on by Moreau [1], who has contended [2], contrary to the generally held opinion that the potato is essentially a long-day plant, that potatoes can give a good yield at high altitudes in East Africa. Driver and Hawkes [3] state that 'the conditions most suitable for maximum tuber yields would seem to be long days to stimulate vegetative growth, followed by short days to turn the plant activity towards efficient tuberization. These are the conditions under which potatoes are grown in temperate latitudes where the highest yields are obtained.' Rayner [4], commenting on the various opinions as to the photoperiod of the potato plant, points out that the photoperiod may be considerably modified by temperature. In view of these very different opinions it is of interest to compare the temperatures and day-lengths under which potatoes are grown in Cyprus.

First main crop (grown in plains):

Planted: February. Mature: May–June. Maturity-period: 120 days. Length of day (sunrise to sunset): Feb. 1, 10 h. 28 m.; June 1, 14 h. 21 m.

Mean monthly temperatures: Feb. 50·5° F., March 53·5° F., April 64·0° F., May 73·8° F.

During May and early June day shade-temperatures of over 90° F. are very common.

Second main crop (grown in plains):

Planted: August. Mature: Nov.–Dec. Maturity-period: 120 days.

Length of day (sunrise to sunset): Aug. 1, 13 h. 54 m., Dec. 1, 9 h. 59 m.

Mean monthly temperatures: Aug. 83·0° F., Sept. 79·5° F., Oct. 74·0° F., Nov. 60·5° F.

During August the daily maximum shade-temperature is normally about 100° F., and in September and October shade-temperatures of over 90° are common.

Hill crop:

Planted: March–April. Mature: Aug.–Sept. Maturity-period 150 days.

Length of day (sunrise to sunset): April 1, 12 h. 53 m., Sept 1, 12 h. 34 m.

Mean monthly temperatures: March 39·3° F., April 54·6° F., May 63·6° F., June 69·6° F., Aug. 67·0° F., Sept. 65·8° F.

The mean monthly temperatures quoted for the plains and the hills are those recorded at Nicosia (500 ft.) and Trikoukkia (4,000 ft.) respectively.

These three crops cover a considerable range of growing conditions yet each seems to be equally healthy and to yield equally well, giving yields not far below those obtained in the U.K. It is true that the second plains crop gives a higher average yield than the first, thus supporting Driver and Hawkes' statement quoted above, but it is probable that this higher yield is at least partly, if not wholly, due to the fact that the second crop is planted almost exclusively with 'once-grown' seed, whereas the first crop is partly planted with older seed, of which some will be planted in a partially dormant state. The conclusion would seem to be that the gross yield is very largely independent of day length and temperature, and that the maturity period is largely a function of the mean temperatures at which the potatoes are grown. The low yields obtained in some parts of the tropics where conditions would appear to be no worse for potato-growing than in Cyprus may be partly due to disease and partly to the general low standard of cropping which is usually accepted by tropical cultivators. It is useless trying to grow potatoes in Cyprus without applying a reasonably good dressing of manure and/or inorganic fertilizers.

(*b*) *Use of 'rose-ends'*.—Small pieces of the potato tuber, containing one or more 'eyes', have long been used as seed. In some countries, however, e.g. the U.K., where it has become the normal practice to plant whole tubers as seed, the question of using seed pieces was, as a result of war conditions, raised on two grounds: (i) that an economy of planting material would result, so releasing a greater proportion of the crop for consumption, and (ii) a saving in the bulk and weight of seed material to be transported would be achieved. The latter aspect was particularly important to Cyprus during the war because the amount of shipping

space which could be allotted for shipment of U.K. seed potatoes was limited. Reports from Russia [5] indicated that rose-ends, i.e. seed pieces obtained by cutting off the rose-end of the potato with relatively small amount of flesh included, might give as good crops as normal seed, and claims were even made that by using rose-ends from large potatoes still better crops could be obtained than were usually harvested from normal seed. Sir Geoffrey Evans [6] described experiments carried out at Kew and suggested shipping rose-ends to the Colonies instead of whole tubers.

Two questions regarding the use of rose-ends that required investigation were: (*a*) whether they give as good yields as the usual types of planting material, and (*b*) whether the use of them entailed a saving in the weight of seed. The weight of seed used per acre depends on (1) the average weight of rose-end, seed-piece or seed-tuber planted, and (2) the density of the planting. Various writers [6], [7], [8] have given different weights and planting distances as 'normal' in the U.K., but it would seem that 27 in. between rows and 15 in. in the row, giving approximately 15,500 plants per acre, is a reasonable average planting density and 2 oz. (57 gm.) sets, corresponding to $17\frac{1}{2}$ cwt. of seed per acre, is a fair figure for the average weight of seed used.

In Cyprus the native method of planting is to cut rather large-sized seed-tubers into several pieces: as long as each piece contains one good eye it is held to be good enough to plant. The weight of the seed used varies from 9 to 10·5 cwt. per acre, and the weight of each seed-piece from 25 gm. (0·89 oz.) to 31 gm. (1·1 oz.). It was apparent that the possible saving in the weight of seed used was less under Cyprus conditions than might be imagined by anyone familiar only with U.K. conditions. However, in the trials described by Evans only 3 cwt. of seed material per acre was used, the average weight of each rose-end being 0·31 oz. or 8·5 gm. The first trial carried out in Cyprus was laid out in the autumn crop of 1943, before the details of Evans's experiments were available. The seed used was locally grown Up-to-Date and the planting density 15,000 plants per acre. The treatments were:

(*a*) Normal Cyprus method of planting, i.e. small seed-pieces.
(*b*) Rose-ends from potatoes of small seed-size.
(*c*) Whole seed of normal size (in order to allow for the effect of cutting, a thin slice of skin was removed from the heel-end).
(*d*) Rose-ends from large ware potatoes.

The results were as follows:

Treatment	*Weight of seed used per acre* (*cwt.*)	*Average weight of each set* (*gm.*)	*Establishment* (%)	*Yield* (*cwt./acre*)	*Yield corrected for establishment* (*cwt./acre*)
a	11·9	39	75	63·5	68·0
b	12·2	41	95	69·5	59·5
c	18·6	66	61	82·0	74·3
d	12·2	41	69	32·7	42·0
Sign. diff.	..	..	17·3	13	4·1

It will be noticed that the average weight of the rose-ends used was practically the same as the local type of seed-piece. The low establishment resulting from the use of rose-ends from large potatoes (treatment *d*) as compared with rose-ends from small potatoes (treatment *b*) is difficult to understand as the tubers used came from the same crop. It may be due to a dormancy factor, the large tubers having been still partly dormant, it being commonly observed that small tubers tend to sprout before large-size tubers. Comparing treatments (*a*) and (*b*), it is seen that although the establishment in (*a*) was significantly poorer than in (*b*)—for no apparent reason—there was no significant difference between the yields. When the yields were corrected for establishment the local type of seed-piece gave a significantly greater yield than did rose-ends. It seemed likely from this experiment that the use of rose-ends as seed would result in decreased yields. Following receipt of Evans's paper, which indicated that the size of the rose-ends might be considerably reduced, a further trial was carried out on the first main crop, 1944.

In this trial imported seed of Up-to-Date and Arran Banner was used. The planting density was 15,000 plants per acre. The treatments were:

(*a*) Up-to-Date planted in the usual Cyprus fashion, i.e. in seed-pieces.
(*b*) Up-to-Date rose-ends.
(*c*) Arran Banner planted in the Cyprus fashion.
(*d*) Arran Banner rose-ends.

All treatments gave good establishments and the results were:

Treatment	*Aver. weight of set (gm.)*	*Weight of seed used per acre (cwt.)*	*Yield (cwt./acre)*
a	36	10·6	93·8
b	22	6·5	78·8
c	36	10·6	89·5
d	22	6·5	60·3
Sign. diff.	..	..	24·5

The standard error in this trial was unfortunately large but the results in general confirm those obtained in the previous trial, namely, that the use of rose-ends as seed reduces the yield. Provided that rose-ends were actually planted by the farmer at the same density as that at which he would normally plant seed-pieces, it appeared that a saving in seed material of about one-third could be achieved at the expense of a reduction in yield of perhaps 15 per cent.

It is, however, probable that in practice the farmer would not plant rose-ends of the above, or smaller, size at the same distance apart as for normal seed-pieces. An example of what would be likely to happen was provided when about a fortnight after the trial referred to above had been started, 90 pieces each of 'cut eyes' (single eyes excised from the tuber with a piece of flesh attached) and rose-ends (variety unknown) reached Cyprus from the U.K. Unfortunately they were not weighed on arrival, but they appeared to be somewhat smaller than the rose-ends used in the trial. Some of this diminution of size may have been due to

drying in transit. These cut-eyes and rose-ends were handed over to the officer in charge of the Central Experimental Farm with instructions that they be planted alongside the rose-end trial described above for comparison. This was done, but the whole 180 pieces were planted in alternate rows in a bed 12 ft. × 24 ft., which gave a density of 27,225 plants per acre, or almost double the normal density used at the farm.

At a density of 27,000 pieces per acre, and assuming a fresh weight of 22 gm. per piece (the weight of rose-end used in the second experiment above), the amount of seed used would be 11·7 cwt. per acre—slightly more than the quantity used by the Cyprus farmer.

These rose-ends and cut-eyes actually did very well. They gave practically 100 per cent. establishment and yields equivalent to 183 cwt. and 189 cwt. per acre respectively. No conclusions could be drawn from these yields as they were obtained from a single small plot.

One further point to emerge related to the fact that experiments (described later) had shown that once-grown seed lifted in June could be kept in cold storage until the following January when it compared favourably with newly imported seed. This, however, entailed the high cost of cold storage for 6 months, together with transport to and from the store; but if a reasonable crop could be produced from rose-ends of a small enough size it might be worth while keeping them in cold storage from one season until the next. Only one trial with this idea in mind was carried out. In July 1944 rose-ends were cut from 'once-grown' Arran Banner and Up-to-Date. The cut surfaces were allowed to suberize, and the rose-ends were then sacked and placed in cold storage (0°—3° C.). They were taken out of storage in January 1945, and the following table shows the effect which the treatment had on the seed-pieces:

	No. rose-ends put in cold storage	*No. sound rose-ends after cold storage*	*Aver. weight per rose-end when put in cold storage*	*Aver. weight per rose-end after cold storage*
Up-to-Date .	1,238	1,160	0·36 oz.	0·26 oz.
Arran Banner .	1,206	1,154	0·44 oz.	0·34 oz.

The varietal difference in weight of the rose-ends appeared to be partly due to difference in density and partly because the more oval-shaped Up-to-Date tuber permitted a smaller amount of flesh to be removed in the rose-end.

These rose-ends were planted in a trial along with similar rose-ends cut from newly imported Up-to-Date and Arran Banner. The establishment and yield were:

	Up-to-Date		*Arran Banner*		
	Cold-stored rose-ends	*Rose-ends from new seed*	*Cold-stored rose-ends*	*Rose-ends from new seed*	*Sign. diff.*
Establishments: plants per acre . . .	6,340	11,900	14,000	13,900	2,400
Yield, cwt. per acre .	18	31·8	71	29·4	9·5

The yields from the rose-ends were disappointingly low, especially as the trial was planted alongside and treated identically with a yield-trial in which Arran Banner and Up-to-Date, grown from newly imported seed identical in origin with that used in the rose-end trial, yielded 208 cwt. per acre and 196 cwt. per acre respectively.

Summing up the results of the various trials it can only be said that, in general, yield from rose-ends is likely to be less than yield from ordinary seed-pieces. Rose-ends could probably be shipped from the U.K. to Cyprus as propagating material without very great losses in transit, and they could probably be kept in cold storage for some months without coming to much harm, but considerable varietal differences appear to exist both in the reaction of the rose-ends to cold storage and in the yields which they might give as compared with normal methods of seeding. For the reasons stated above it is doubtful whether in practice any actual saving of seed material would result, because the ordinary farmer would tend to compensate for the smallness of the seed-piece and the probable reduction in yield by planting the sets closer together. Further trials on varietal responses and methods of handling and storage would be necessary before definite recommendations could be made. As conditions in the Mediterranean were tending towards normal by July 1945, further investigations were dropped.

Breaking the dormancy.—As mentioned in the introduction, one of the main objections to the use of Cyprus seed for the first main crop (spring) planting is that seed from the November lifting is still dormant when the time for planting comes round in February. The Cypriot farmer is aware of the desirability of ensuring that the dormancy has been broken before planting, and in the main potato-growing areas seed potatoes lifted in November are often placed in straw either in a warm room or in a sunny corner of the yard and kept moist. This 'sprouting' treatment does not induce growth of the sprouts but does hasten the natural breaking of the dormancy, as the following results of a trial showed:

Yield from untreated seed . .	51·8 cwt. per acre
Yield from 'sprouted' seed . .	73·0 cwt. per acre
Significant difference . . .	6·1 cwt. per acre

Other methods of obtaining suitable seed from local material from spring planting have been tried: these are:

(*a*) Treatment with ethylene chlorohydrin solution; 1 pint of 4 per cent. ethylene chlorohydrin to 4 gals. of water. The cut seed-pieces are immersed in this solution long enough to become well wetted and are then placed in a closed drum and planted the following day.

(*b*) Treatment with acetylene solution [9]. Eight oz. of commercial calcium carbide are added slowly to 11 gals. of water so that the acetylene produced is as far as possible completely taken up in solution. The uncut seed is then placed in the solution for 4–5 hrs. and on removal is ready for planting.

(*c*) Treatment by cold storage. Seed from the June lifting is clamped for about one month and then placed in cold storage (0°—3° C.). It is removed the following January, spread out in an open shed, and allowed to sweat until it reaches normal air-temperature. When removed from

cold storage the eyes are nicely swollen and the seed is in excellent condition for planting. It is impossible in the Cyprus climate to keep tubers from June till January by any means other than cold storage.

(*d*) Use of hill seed. Seed from the hill crop lifted in September is kept in good, airy dry-stores and is ready for planting by January–February.

Table 3 shows the yields obtained in various trials from different types of seed including newly imported seed. All experiments were, of course, carried out on the first (spring) crop.

TABLE 3. *Yield from Various Types of Seed* (*cwt. per acre*)

Year and soil	*1943 Alluvial*	*1944 Alluvial*	*1944 Terra rossa*	*1945 Terra rossa*	*1945 Alluvial*	*1945 Alluvial*
Type of seed *Variety*	*Up-to-Date*	*Up-to-Date*	*Up-to-Date*	*Up-to-Date*	*Up-to-Date*	*Arran Banner*
(*a*) Cyprus-grown seed untreated in any way	18·6	33·3	19·9	58·2*	..	..
(*b*) Seed similar to (*a*) treated with acetylene solution	50·3	40·0	38·6	67·1*	..	..
(*c*) Seed similar to (*a*) treated with ethylene chlorohydrin	..	37·6	24·4	..	..	..
(*d*) Seed lifted in June and kept in cold storage	60·9	38·3	36·4	120†	83·5†	61†
(*e*) Seed from the hill crop	..	..	52·1	90·0	59·3	..
(*f*) Newly imported seed	..	..	75·9	113	141	112
Sign. diff.	13·2	8·0	11·3	10·7	12·4	10·9
(*g*) Newly imported seed treated similarly but not included in the above trials	..	87·2	..	..	..	..

* Twice grown. † Once grown.

All Cyprus-grown seed in 1943 and 1944 had been grown for several generations in Cyprus, the last importation of Up-to-Date having been made in 1940. In 1944 the seed had been grown for not less than 4 and probably not more than 8 generations.

It is clear that all the treatments tried for breaking the dormancy are at least partially successful, though in many cases the increases in yield obtained are not statistically significant. The results are, however, complicated through the fact that, as the 'age' of the seed increases, the potential yield decreases, due to increasing virus-content. (This problem is briefly discussed below.) In the 1943 trial, for example, it was possible to increase the yield of locally grown untreated seed (5 or 6 times grown from imported seed) to a maximum yield of about 60 cwt. per acre. In 1944, when the seed was 2 generations older, the maximum yield under the same treatment appeared to be about 40 cwt. per acre. Apart from this complication, however, there is no doubt that by suitable treatment of dormant seed it is possible to hasten the breaking of the dormancy and so increase the resultant yield. Of the treatments tried, by far the simplest other than 'sprouting', and probably the most effective, is the cold storage of seed from July till January. This has the added advantage that it cuts out one generation during which further virus infection would occur. The only practical difficulty is that the cost (and trouble) of transport to and from the existing cold stores, together with the cost of storage, is more than the average peasant farmer is prepared to face. The two chemical treatments are tedious and require

a certain amount of intelligent supervision. The acetylene treatment is cheaper and appears to be more effective, but experience in Cyprus is that the tubers should be planted immediately after treatment, otherwise fairly heavy rotting may set in. This is a disadvantage, since the treatment is most conveniently carried out the day before it is intended to plant, and a breakdown of the weather between treatment and planting may result in delay and loss of seed. The use of hill seed is, of course, simple and is practised to a considerable extent. The quantity of this seed available is, however, small and as the crop is grown in very small terraces by a multitude of peasant small-holders it is very difficult to commercialize the crop on a large scale. The hill seed, too, often tends to be several-generations grown in Cyprus, and increased virus infection may obviate any advantage gained from obtaining seed whose dormancy has been broken.

Seed Certification.—During the war years the average yield of potatoes was falling owing to the increasing amounts of various virus complexes that were being distributed through the stocks. Table 1 illustrates the general drop in yields between 1939 and 1943. Comparisons of the yields obtained in 1943, 1944, and 1945 (Table 3) are also illuminating. In 1945 a comparison was made between once-grown seed which had been lifted in June 1944 and kept in cold storage and old seed 7 or 8 times grown also lifted in June 1944 and kept in cold storage. The yields obtained were 120 cwt. and 37·3 cwt. per acre respectively (significant difference 10·7). The figures quoted should be sufficient to demonstrate the seriousness of 'degeneration' in Cyprus. The commonest acute symptom of virus attack is leaf-drop streak which, especially on Up-to-Date, can be almost lethal.

In order to offset the shortage of imported seed a local potato seed-certification scheme was started in 1944, based on field inspection of the growing crop. Seed older than 'twice-grown' is not inspected. The various difficulties which have been met in operating this scheme cannot be discussed here, but some of the results obtained in testing the certified seed in two trials carried out with Up-to-Date in the first (spring) crop 1945 are given in Table 4.

TABLE 4. *Yield from Various Types of Seed* (*cwt. per acre*)

	I	*II*
Imported seed	141	113
Locally certified once-grown seed lifted June 1944 and kept in cold storage	83·5	120
Uncertified once-grown seed lifted June 1944 and kept in cold storage	41·3	..
Locally certified twice-grown seed lifted in Nov. 1944 and treated with acetylene to break the dormancy	..	67·1
Old seed, 7–8 times grown, lifted in June 1944 and kept in cold storage	..	37·3
Sign. diff.	12·4	10·7

The evidence demonstrates that inspection and certification can go far

towards raising the general level of potato yields. Even in normal times only about half of the first (spring) crop was planted with imported seed, the remainder being planted with local seed. The use of locally certified once-grown seed for the second (autumn) crop and locally certified twice-grown seed for that part of the first (spring) crop not planted with imported seed, would result in a general raising of average yields. The use of such seed is increasing, especially in those villages which make a practice of breaking the dormancy by some form of treatment.

Summary

1. The conditions under which potatoes are grown in Cyprus are described.

2. Trials have shown that early varieties do not mature any earlier than maincrop varieties and their yield is much less. Up-to-Date is consistently the best yielder.

3. Experiments indicated that the yield from rose-ends is less than that from the normally used cut seed-pieces, and that no saving in the total amount of seed material would be gained by using rose-ends.

4. Various methods of obtaining, for spring planting, seed with the dormancy broken are described, and the results of experiments show that it is relatively easy to obtain such seed. Various difficulties limit the application of such methods under peasant-farming conditions.

5. The extent of 'degeneration' of Cyprus potato stocks during the war years is described, and figures are quoted from experiments demonstrating that 'degeneration' can be controlled by a system of field inspection and seed certification.

REFERENCES

1. R. E. Moreau, Empire J. Expt. Agric., 1944, **11**, 13.
2. —— East Afr. Agric. J., 1944, **9**, pp. 127, 203.
3. C. M. Driver and J. G. Hawkes, Photoperiodism in the Potato. Imp. Bur. Plt. Breed. & Gen., 1943, Tech. Comm.
4. R. W. Rayner, East Afr. Agric. J., 1915, **11**, 25.
5. Information supplied by the M.E.S.C. from reports from Russian sources.
6. Sir Geoffrey Evans, Nature, 1943. No. 3860, p. 464.
7. U.K. Ministry of Agric., Bull. No. 94.
8. N. L. Tinley and D. M. Bryant, J. S. E. Agric. Coll., Wye, 1939. No. 44, 120.
9. J. Counc. Sci. and Ind. Res., Australia, 1942, **15**, 253.
10. K. M. Smith, A Text-book of Plant Virus Diseases, 1937.

(*Received December 19, 1946*)

SOME SOIL PROBLEMS OF EMPOLDERED RICE LANDS IN SIERRA LEONE

J. M. DENT
(*Agricultural Officer, Sierra Leone*)

THE first polder constructed by the Department of Agriculture in Sierra Leone was at Maswari in the Colony Peninsula in 1939. The early history of this scheme has been reported in detail by Macluskie [1]. Originally the area was partly under grass and partly under Avicennia mangrove. The land was inundated by the tide and the soil contained too much salt for rice to be grown. At first yields were disappointing: later conditions improved, then relapsed; but finally, after some years, reasonable crops were harvested.

From 1943 onwards, large-scale schemes for the reclamation of swamps by empoldering were begun at Maswari and Wellington in the Colony Peninsula, and also at several places on the banks of the lower reaches of the Great Scarcies river. Of the Scarcies schemes only those at Rosino and the Luti-Funkadeh area are considered in this article.

The Maswari scheme was an extension of the original polder built in 1939. The vegetation is mainly Avicennia mangrove, but there is some Rhizophora mangrove. As in the original area reclaimed, excessive salinity of the soil precluded the growth of rice. Similar conditions prevailed at Wellington.

The two Scarcies schemes quoted are situated some 15 miles from the mouth of the river, which is in the north of Sierra Leone. The tidal water is salt during the latter part of the dry season, i.e., from March to May. The Rosino swamp is a grass swamp which was too deeply flooded for the successful growth of rice. The Luti—Funkadeh area is similar, except that there is a considerable stand of Rhizophora mangrove near Funkadeh and a small amount at the Luti sluice. During the dry season of 1944, the Rokupr Experimental Rice Farm, formerly tidal, was empoldered. This station is also on the Scarcies river, but 20 miles from the mouth. Originally, the vegetation was a mixture of Rhizophora mangrove and Raphia-palms, with some oil-palms and a few other trees.

In all of the areas, the soil is a blue-grey clay, frequently mottled yellow or red, and covered with a variable amount of organic matter partly decomposed.

Observations

The first indications of soil problems in empoldered areas, apart from those of soil salinity, appeared at Rokupr in 1945. In 1944, rice was planted in July immediately after bunding had been completed, and it soon became clear that over most of the farm a good yield was to be expected, but high-lying blocks adjoining the upland supported poorer crops, presumably owing to the difficulty of holding water on these areas. On six blocks near the river, however, the rice died in patches though

elsewhere in the same blocks growth was good. In general the harvest was reassuring. The 'dead spots' were attributed to disturbances of the soil and subsoil when the bunds were made and the blocks levelled, and the opinion was held that they would disappear in time as the soil reverted to its natural state and as the salt leached out.

After harvest, in early 1945, river-water was excluded from the farm to test the possibilities of growing crops other than rice during the dry season. Later when rice was planted it was noticed that the 'dead spots' had enlarged considerably since the previous year, and that in the affected areas yields would be very poor. Simultaneously, all vegetation except mangrove was killed at Funkadeh. No rice was planted there; but at Luti, near the sluice, rice died in the same way as it did at Rokupr. In both these areas water had been excluded in the dry season. The failure of comparatively large areas of rice caused great concern, especially as the phenomenon appeared to be quite new. About this time the term 'soil toxicity' came into vogue to describe the unaccountable necrosis of rice in certain areas.

The toxic syndrome presented several typical features. The leaves of the rice became rusty in colour; the plants were stunted and usually died; the soil became red, and red alga-like growth frequently occurred.

A careful scrutiny was made of the records of Rokupr Farm since its inception in 1934. This investigation showed that the blocks worst affected in 1945 had always exhibited localized differences in fertility. Many references were made to obscure diseases of rice occurring in small patches and characterized by symptoms identical with those described above. It appears, therefore, that pockets of toxic soil have been present at Rokupr at least since 1934, but until 1945 the total effect was so slight that no serious apprehension was felt.

Early in 1946, when the problem could no longer be overlooked, steps were taken to investigate the chemical relationships of the toxic substances. It was rapidly established by analysis of soil samples and water samples that in affected areas there was a high concentration of iron and sulphate, coupled with very high acidity. Analyses were made by M. Gosden, the Senior Pathologist, Sierra Leone, R. G. Willcock, the Government Chemist, Gold Coast, and by the author. All agreed that the samples contained a mixture of iron sulphates which had become partially hydrated. As a typical case, an analysis of water from Block 22, Rokupr Farm, is given in Table 1. Standard gravimetric or volumetric methods of estimation were used.

TABLE 1. *Analysis of Water from Block 22, Rokupr Farm*

pH	*Less than 3*
Iron (as Fe_2O_3)	1·24 per cent.
Sulphate (as SO''_4)	1·74 ,,
Chloride (as Cl')	0·22 ,,

Water from toxic areas had a typical dark reddish-brown colour and was acid and astringent in taste. These characteristics made chemical analysis frequently unnecessary. The presence of iron and sulphate was

confirmed in samples of soil and of water from certain areas at Luti, Funkadeh, the large Maswari polder, and Wellington, and it was suggested that early failures in the original Maswari polder were due in part to the same toxic substances, and not entirely to excessive salt.

A chance observation was made when an excavation for a boat-house was being dug at the edge of the river at Rokupr. It was noticed that many undecomposed mangrove roots occurred in the wall of the cutting, and from each root, which acted like a wick, ran a trickle of ferruginous water leaving a rusty streak on the face of the cutting. This observation was subsequently repeated on the sides of drains and other excavations. Together with the distribution of toxic areas in relation to their former stand of vegetation, these findings led to the assumption that mangroves and toxicity were interrelated.

At Rosino the 1946 crop became progressively poorer from the part nearest the river to the back of the swamp, but no evidence of iron, sulphate, or chloride was found. In this swamp the organic horizon overlying the clay is from 3 to 4 in. thick near the river, but as much as 6 to 8 in. at the inner end.

In January 1947 the writer visited the Maswari and Wellington polders to obtain further data on soils in empoldered areas. Notes were made of the distribution of vegetation and of the condition of the rice as estimated from the stubbles. Soil samples were taken, and soil profiles studied. Most soil samples were taken in pairs, one sample from a place where rice thrived and the other (frequently within a few feet of the first) from where rice had failed. Aqueous eluates of the samples were examined qualitatively for Cl', SO''_4, and Fe''' ions. The pH of the eluate was determined by Universal Indicator, and the presence of iron compounds insoluble in water determined by testing in an extract with dilute nitric acid.

The vegetation was of three kinds. At Maswari, most of the vegetation was Avicennia mangrove, with some grass and some Rhizophora mangrove. At Wellington, only Avicennia mangrove and Rhizophora mangrove occur. Grass occupies the least saline areas. Avicennia, which is shallow-rooted, prefers low-lying ground, tidally inundated, but with impeded surface-drainage. Water collects in such areas, and any salt present is concentrated by evaporation of the water. Avicennia mangrove must therefore tolerate considerable quantities of salt. Rhizophora mangrove has fibrous roots penetrating deep into the soil; it grows on low-lying tidal lands where there is free surface-drainage, i.e., although it can tolerate fair concentrations of salt, moving water appears necessary for its well-being.

Profiles in each area are typical. Grass is associated with a layer of organic matter from 3 to 8 in. deep. The organic layer in Avicennia areas is thin, only 1 to 3 in., whilst in Rhizophora areas the peaty horizon is from 3 to 6 in. deep.

Similarly, the pH of the soils vary: Rhizophora soils are usually acid, Avicennia and grass soils are about neutral.

When clay from either a Rhizophora or an Avicennia area is exposed to the weather, acid deposits of ferric sulphate appear frequently, and

water flowing from such material may be highly ferruginous. These deposits have been noticed on the bunds at Rokupr, Luti, Funkadeh, Wellington, and Maswari. A piece of clay from the subsoil of Rokupr Farm was exposed to the weather and determinations of pH, sulphate, chloride, ferrous and ferric iron made at intervals (Table 2). It must be understood that the facilities for estimations were poor, and the designations 'slight', 'much', &c., were made from visual estimation of precipitates or colorations from an aliquot part of an eluate. The table therefore is given only as a rough guide.

TABLE 2. *Effect of Weather on Scarcies Clay*

Date	*pH*	*Cl'*	*SO''_4*	*Fe''*	*Fe'''*
8.8.46	9·4	Trace	..	..	..
23.8.46	7·4	..	..	..	..
30.8.46	5·0	..	..	Trace	Slight
9.9.46	4·4	..	Trace	Slight	Slight
18.9.46	4·2	..	Very slight	Much	Much
25.9.46	4·4	..	Slight	Much	Much

Regarding the production of sulphate, it was noticed, both at Rokupr and Wellington, that when digging in Rhizophora areas, the characteristic smell of hydrogen sulphide sometimes occurred. This has not been reported in Avicennia areas.

A peculiar phenomenon in Avicennia areas, as typified by the New Maswari polder and Wellington, is that rice thrives immediately around Avicennia stumps, but dies beyond the radius of root-spread of the tree as delineated by the pneumatophores. Profiles near stumps and away from stumps appeared identical and analyses of samples gave inconsistent results.

A still more remarkable fact in connexion with Avicennia mangrove was observed at Maswari. Along the main bund, and in the spoil from drains, were found what on first sight appeared to be small pebbles. On examination, these were seen to be fragments of Avicennia roots which had become coated with a thick concretion of iron oxides. A careful search was made but no similarly coated roots of Rhizophora could be found, although the roots themselves were abundant where the bund or drain ran through a Rhizophora area.

Much of what has been stated in the previous paragraphs is summarized in Table 3, which gives the analyses of the samples taken at Maswari and Wellington.

Discussion

From the preceding observations made at various times by different members of the Agricultural Department, it appears that at least three soil factors, working singly or in combination, are responsible for complete or partial failure to grow rice in any given area. These are: an excessively thick superficial layer of peaty matter; a high concentration of common salt; and the presence of toxic quantities of iron sulphates, coupled with high acidity.

TABLE 3. *Analyses of Soil Samples taken at Maswari and Wellington*

	Sample	Original Vegetation	Rice	pH	Cl'	SO''_4	Fe''	Fe'' HNO_3 extract	
Original Maswari polder	A	Grass	Fair	6·5	Trace	−ve	−ve	+ve	3–4 in. peaty organic matter overlying grey clay mottled yellow
	B	Grass	Fair	8·0	Trace	−ve	−ve	+ve	,,
	C	Avicennia	Good	8·0	Trace	−ve	−ve	+ve	2–3 in. peaty organic matter overlying the same clay.
New Maswari polder	D	Avicennia near stump	..	8·0	+ve	−ve	−ve	Trace	,,
	E	Avicennia away from stump	..	8·0	−ve	Trace	−ve	+ve	,,
	F	Avicennia	..	..	..	..	..	..	Petrified roots
	G	..	..	6·5	+ve	−ve	−ve	+ve	Pocket of red clay in grey clay sub-soil
	H	Avicennia near stump	Fair	8·0	+ve	−ve	−ve	Trace	2–3 in. peaty organic matter overlying grey clay mottled yellow
	I	Avicennia away from stump	Failed	6·5	+ve	−ve	−ve	+ve	,,
	J	Rhizophora	..	6·5	+ve	−ve	−ve	+ve	6 in. peaty organic matter overlying unmottled grey clay
Wellington	A	Rhizophora	..	<3	+ve	Trace	−ve	+ve	4–5 in. peaty organic matter overlying grey clay mottled yellow
	B	Rhizophora	Failed	<3	+ve	−ve	−ve	+ve	3–4 in. peaty organic matter overlying same clay
	C	Transition Rhizophora Avicennia	Fair	5·5	+ve	−ve	−ve	+ve	1–3 in. peaty organic matter overlying same clay
	D	*Sesuvium portulacastrum* ex Avicennia	Very good	8	−ve	−ve	−ve	+ve	,,
	E	Avicennia away from stump	Failed	3·5	+ve	−ve	−ve	+ve	,,
	F	Avicennia near stump	Fair	5·5	+ve	−ve	−ve	+ve	,,
	G	..	..	<3	+ve	+ve	+ve	+ve	Deposit off bund
	H	Avicennia near stump	Fair	<3	+ve	−ve	−ve	+ve	1–3 in. peaty organic matter overlying grey clay mottled yellow
	I	Avicennia away from stump	Failed	<3	+ve	−ve	−ve	+ve	,,

In grass swamps, e.g., in part of the original Maswari polder, and in the Rosino polder, the thickness of the peaty layer appears to be the deciding factor. Rice is a shallow-rooted plant and cannot be expected to grow well in a soil, the top 6 in. of which are of such poor texture and poor nutrient status. This aspect of the Maswari soil was commented upon by Macluskie [1].

On *a priori* grounds, continued deep cultivation of such soils, thus incorporating the peat with the clay, should produce some amelioration

of conditions. However, these soils contain combined iron, and such a procedure, by exposing the clay to the air, might bring about other undesirable effects. Experience in the original Maswari polder, which has been cultivated since 1939, indicates that this fear is unfounded, for the samples taken there were neither acid nor contained soluble iron compounds.

The peat layer in Rhizophora areas is a complicating factor, but not the major one.

Common salt, though of considerable significance for the first few years, is not of lasting importance. Much rice is successfully grown on tidally inundated land in the Scarcies area, where the water is salt for three months of the year. In the original Maswari polder, the salt in the soil is now negligible, showing that leaching is almost complete.

It is the toxic-iron problem that is of paramount importance. The high acidity of Scarcies swamp soils and the solvent effect of the acid on iron compounds were first observed by Glanville and Doyne [2]. These workers believed that the acidity was due to hydrochloric acid, and postulated an NaCl-organic acid complex exchange. They did not apparently detect the presence of sulphate. Further, they noted that the acidity was highest in newly cleared mangrove swamps, and even after many years the subsoil remained acid, though the top 6 in. became nearly neutral.

In 1937 Doyne and co-workers, investigating cleared mangrove swamps in Nigeria, found that the pH of these soils fell rapidly when exposed to the air, that red ferruginous streaks appeared, and that ferrous iron and sulphate were produced [3, 4]. They believed that the acidity and the occurrence of iron sulphate was caused by the oxidation of ferrous sulphide, thus producing sulphuric acid. This hypothesis seemed to fit the facts found in Sierra Leone, and Doyne's observations were confirmed at Rokupr. Mr. Pollett, Government Geologist, reported finding deposits of iron pyrites in association with rotting mangrove vegetation in the Colony Peninsula near Maswari. Under the influence of air and water, pyrites would oxidize to ferrous sulphate and sulphuric acid. However, it is possible that the first step in the reaction is the conversion of oxides of iron, which are common in the soil, to the sulphide, through the action of hydrogen sulphide produced during the decomposition of mangrove residues. Under natural conditions, periodic inundation of the soil by the tides produces relatively anaerobic conditions, which inhibit the final oxidation. When water is artificially excluded from the soil, as when an area is empoldered, the reaction is allowed to proceed unimpeded. Arguing along the lines that the reaction suggested does take place, flood-fallowing in the dry season ought, by restoring anaerobic conditions, to inhibit the further production of ferrous sulphate. Experiments are being carried out at Rokupr to determine if this is so, and whether there is any optimum period for the flood-fallow. No reliable results can be expected until several years have passed, though preliminary indications are promising.

Toxicity in Avicennia areas appears to be of a more transient nature than toxicity in Rhizophora areas. In the original Maswari polder the

old Avicennia area now supports the best crop of rice. At Wellington, owing to improved drainage, part of the area which was once a pure stand of Avicennia has now become practically free from salt. This part of the swamp is now covered by a vigorous growth of *Sesuvium portulacastrum*, and plots of rice in this area have given excellent yields.

It is difficult to suggest reasons for the inter-species difference. The thinner layer of peat associated with Avicennia mangrove, and the comparative neutrality of the soil in which it grows make conditions potentially more suitable for the growth of rice. The unique formation of iron-oxide concretions on dead Avicennia roots is also undoubtedly concerned. Perhaps Avicennia mangrove, which withstands high concentrations of common salt, can also tolerate considerable concentrations of other ions, and possesses sap constituents that precipitate soluble salts of metals, rendering them harmless. The physiology of both species of mangrove requires full investigation before the answer to the iron—mangrove reaction can be ascertained.

Summary

1. The history of empoldering in Sierra Leone is outlined, and subsequent soil problems are described.

2. Three soil factors, viz., excess of organic matter, excess of salt, and a toxic concentration of iron sulphates, coupled with high acidity, are responsible, either singly or in combination, for total or partial failures to grow rice. The first two factors are relatively unimportant.

3. The presence of toxic iron compounds is associated with mangrove vegetation, and these compounds are believed to be produced by atmospheric oxidation of ferrous sulphide.

4. Toxicity due to iron compounds, as produced in areas of Avicennia mangrove, seem to be less lasting than toxicity in Rhizophora mangrove areas.

Acknowledgements

The writer is indebted to the Director of Agriculture, Sierra Leone, for permission to publish this article; to colleagues in the Department, especially Mr. H. Macluskie, who have offered information, suggestions, and criticisms; to the Pathologist, Sierra Leone; and to the Government Chemist, Gold Coast, for analyses of samples of soil and water.

REFERENCES

1. H. Macluskie, Field, Farm and Forest, 1943, **4**, 4. (Nigerian publication.)
2. R. R. Glanville, and H. C. Doyne, Some Swamp Soils of Sierra Leone. Trop. Agric., 1933, **10**, 132.
3. H. C. Doyne, Acidity of Mangrove Swamp Soils. Ibid. 1937, **14**, 286.
4. —— Hartley, and Watson, Soil Types and Manurial Experiments in Nigeria. West Afr. Agric. Conf., 1938.

(*Received May 12, 1947*)

INDIAN CATTLE IN THE UNITED STATES OF AMERICA

SIR FRANK WARE

WITH PLATE 7

DURING a recent visit to the United States I was accorded the privilege and great pleasure of seeing some of the cross-breeding work which is being carried out in the southern States between Brahman (Zebu) cattle and such breeds as the Hereford, Aberdeen Angus, Shorthorn, and the so-called native cow, which is thought to be a descendant of the animals originally imported by the Spaniards.

Travelling from California, as soon as one enters Texas State, a visitor from India is struck by the large proportion of so-called Brahman cattle to be seen on the ranches in this State, as well as in the neighbouring States of Georgia, Louisiana, and Florida, and one soon learns that as much interest is taken in the breeding of these cattle in the west as in India itself: in fact, judged by the number of Brahman Cattle Breeding Associations existing in the States, not to mention the adjoining territories of Mexico and South America, these Zebu cattle are receiving more attention abroad than in their own country.

But the manner in which the subject is being dealt with in the west does not conform to the standards recently set by Indian authorities, who have devoted much time in recent years to separating and purifying the different breeds of Zebu cattle which exist in India, all of which show marked variation in their potentialities as producers of the different commodities required by man, with a view to their maximum development in that line which suits them best.

In an article entitled 'The Cattle of India and their Development' [1], I referred to 25 breeds of Zebu cattle and attempted to arrange them in 5 main groups, and more recently an American worker, Phillips [2], whilst accepting my general system of classification, has added to the number of breeds and has entered a plea to drop the specific terms 'Brahman' and 'Zebu' as used in America, and adopt the breed names by which these cattle are known in their native country, i.e. India.

I heartily endorse that view, for to an Indian worker it is confusing to be shown animals of such widely different breeds as the Kankrej (Guzerat) and Krishna Valley or Hariana (Plate 7, figs. 1, 2), and hear that they are all included in the same herd-book, provided they are of pure Indian descent.

Incidentally, it was of great interest to see the result of long-continued mixing of these breeds, which appear to be those most commonly imported in the past into this part of the States, although others, like the Gir and Ongole (Nellore), have been used farther south. The Kankrej and Hariana breeds were placed in separate groups in the previous article referred to above [1], and it was not surprising, therefore, to find a lack of uniformity in the herd, but the prevailing type of so-called Brahman cattle in this part of America is very like the upstanding

light-grey animal which has been produced by very similar methods at the Hissar Cattle Farm, Punjab, India.

The solution of the rather confused state of affairs existing at present appears to be for the authorities concerned with the administration of one or more of the American Brahman Cattle Herd-books to get in touch with the Secretary, Imperial Council of Agricultural Research, New Delhi, India, whose Animal Husbandry Bureau is responsible for the selection of animals admitted to the Indian herd-books, and see if a common line of action can be agreed upon.

Indian herd-books have been opened *inter alia* for the Kankrej (Guzerat), Hariana, Sahiwal, Sindhi, Gir, and Ongole (Nellore) breeds. Breeders in both North and South America, and in Mexico, have already imported several of these breeds and it is probable that they would be interested in the importation of some more highly developed specimens of these same breeds, and also other breeds, if they knew more about their performances. The Sahiwal, for instance, has been successfully imported into Kenya Colony, East Africa, in recent years for crossing with imported English breeds with a view to the production of an animal giving a good quantity of milk and offering resistance to heat and disease.

So far the Zebu in America has been used almost solely amongst range cattle for the production of beef stores, and for this purpose, even in the mixed manner in which it has been allowed to develop, has proved very successful. It seems reasonable to suppose, however, that if more attention were paid to the selection of Zebu breeds known to make good beef animals, such as the Gir and the Sahiwal, even better results would be obtained by American breeders.

One objection to the use of Zebu animals, which is often voiced not only from America but also from North Australia, where similar use is being made of them, is their wildness, but this applies only to the grey breeds, such as the Kankrej and Hariana, which are notoriously wild when kept under range conditions in their own country. Breeds like the Gir, Sahiwal, and Sindhi, which are all good milch breeds, are, however, as docile and tractable as any English breed.

The conditions under which cattle have to live in the southern States of America simulate very closely those obtaining for the Zebu in India, but on the whole they are easier, and this no doubt accounts for the way they have thriven abroad. Grazing on the ranches is abundant, except during the winter, which is short. Concentrates are fed only in the winter, and much work is being done on the improvement of the grazing by the introduction of good grasses like St. Augustine, Pangola, and Bermuda grass, the latter closely resembling the Indian *dhub* grass in its habits.

The one great bugbear of graziers in the southern States is a stunted palm, locally known as Palmetto (Plate 7, fig. 2), which has to be removed before fodder grasses will thrive. This can be done by the use of bulldozers, but the most effective way to rid an area of this pest is to graze it heavily with animals deprived of any other kind of green fodder. Considering the toughness of the palm leaf, it is difficult to

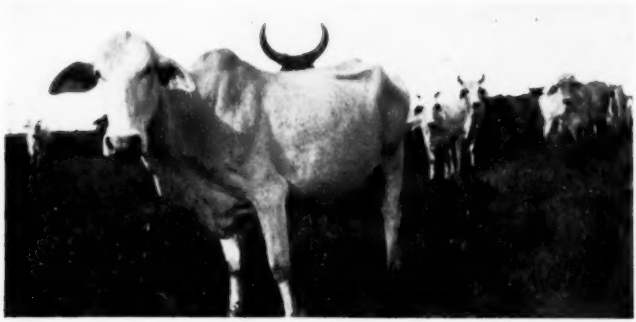


FIG. 1. Hariana type of cow in foreground with typical Kankrej head behind.

FIG. 2. A mixed collection. Typical Hariana, Kankrej, and intermediate forms can be seen. Also clumps of Palmetto.

FIG. 3. Santa Gertrudis heifer. 22 months old. Grass fed only

FIG. 4. Santa Gertrudis cow and calf. Note udder development.

believe that cattle can deal with it at all, but it was demonstrated to me that they can do so most effectively if kept under the conditions described.

The infusion of Zebu blood amongst these range cattle results in the birth of a heavier calf which matures more rapidly and makes excellent baby beef at one year old. If kept beyond this age the natural resistance to heat, drought, and insect pests possessed by the cross-bred animal enables it to stand up to range conditions, which are comparable with an Indian summer for part of the year, better than the pure-bred, and when finally killed the dressing percentage is higher.

Similar to the experience in other countries where this cross-breeding work is in progress, e.g. Australia and India, it has been found in the States that an animal with five-eighths European blood best fulfils the requirements, but on most of the ranches it is not possible to do more than use the best-looking available bull, either pure or cross-bred, and hope for the best. This, of course, results in the birth of a number of misfits, but as there is always a ready market available for veal calves, no difficulty is experienced in disposing of these.

A more scientific approach to the subject has been made on the King Ranch, Texas, where, as the result of 20 years' crossing work with Shorthorns and Brahmans (breed not stated), a very useful nearly whole-red beef animal has been produced. This animal is said now to breed true to type, and the breed has been named Santa Gertrudis (Plate 7, figs. 3, 4). It is said to possess all the requirements of a range animal for the southern States, and if it is all that it is claimed to be, it deserves further trial in other tropical countries requiring a beef breed.

What has been done for beef now requires to be done for milk, and it is to be hoped that the work which has been in progress for many years past in the Military Dairy Farms, India, to produce a satisfactory Indian Holstein breed, will be carried through to completion, in spite of the political changes occurring in that country.

Acknowledgement.—I owe my information concerning Indian cattle in the U.S.A. largely to the kindness and hospitality of Dr. M. Jay Flipse of Miami, who is an enthusiastic breeder of Brahman and cross-bred cattle on his Silver Lake Ranch, Florida State. I am also indebted to him for the photographs (Plate 7).

REFERENCES

1. WARE, F., The Cattle of India and their Development. Empire J. Expt. Agric., 1941, **9**, 1–11.
2. PHILLIPS, R. W., The Cattle of India. J. of Heredity, 1944, **35**, No. 9.

(*Received June 10, 1947*)

THE PHOTOPERIODIC REACTIONS OF POTATO BOLTERS

J. G. HAWKES
(*Imperial Bureaux Potato Station, Cambridge*)

WITH PLATE 8

Introduction.—Bolters are variations that occur in many potato varieties and are especially well marked in the first earlies. They differ from normals chiefly in their much later maturity, taller stems, tendency to freer flowering, much longer stolons, and greater yield when allowed to reach full maturity. Bolters can readily be distinguished from normals in a potato field at a time when the latter are beginning to die down by the fact that the bolters possess tall green haulms which are often still flowering.

The bolter condition apparently arises quite suddenly in a potato variety, though it is thought by some to occur in two stages, the intermediate type being classed as a semi-bolter. It seems probable from the negative results of attempts to transmit the bolter condition by means of grafting and inoculation, that bolters are not due to the effect of any pathogenic organism, and the suddenness with which they occur would seem to suggest that they are due to some type of genetic mutation. This hypothesis is supported by the fact, demonstrated by Carson and Howard [1], that the bolter type is inherited from parent to offspring. The frequency with which bolters occur, especially in some of our earliest maturing potato varieties, suggests that they are due to the mutation of an unstable gene or genes. We know nothing as to whether the bolter may mutate back to the normal type for they are naturally not grown in any large quantities, and the reverse mutation, if it occurs, might easily have been overlooked up to now.

In a previous communication [2] the present writer put forward an hypothesis that the bolter is a short-day adapted mutant of the normal long-day adapted potato variety of commerce. This explanation was based on experiments carried out in 1945 in which the variety King Edward was grown in both normal and bolter strains under both long and short days. Under the long summer days of Britain the differences between normals and bolters were very marked. Under artificial short days, however, they were not apparent. This suggested that the bolter was a reversion to the primitive short-day adapted potato type that is to be found in the Andes of South America and from which all our domestic varieties probably stem. When grown under short days of 12 hrs. or less all the primitive undesirable features of the bolter, such as late maturity, tall stems, and long stolons disappeared and it seemed completely normal. This is the same effect as is obtained with the short-day adapted S. American potatoes when grown under long and short days, as the writer has already demonstrated [3]: under long days they mature late and generally possess long stolons and tall stems; under short days, however, they mature early and their stems and stolons are relatively short.

The evidence obtained in the above-mentioned experiments with King Edward potatoes was insufficient for statistical analysis, and the more comprehensive tests carried out in 1946 to confirm the 1945 results form the basis of the present communication.

Materials and methods.—Two varieties from two different maturity groups were used in the present experiments, namely Gladstone—an early main-crop variety—and Sharpe's Express—a first early variety.

Twelve plants were used in each treatment, arranged in a block of 4×3 plants, in pots of $8\frac{1}{2}$-in. diameter sunk in the soil up to the rims and filled with a standard well-mixed John Innes compost. Thus differences in soil and fertility were avoided. The plants under short day were grown in asbestos-covered dark frames with a hinged lid that could be shut at the appropriate time in the evening and opened again in the morning (Plate 8, figs. 1–3). The lids were opened at 8.15 a.m. and closed at 4.45 p.m., thus giving a day-length of $8\frac{1}{2}$ hrs. This, although less than the average of 12 hrs. that plants in the tropics would receive, has been shown to give valid results for S. American potatoes and to be quite satisfactory for all similar experiments on photoperiodism.

The plants under long day were grown with the same spacing as those under short day but were not enclosed in frames. They received the normal summer day-length of the British Isles, which varies roughly from 15 hrs. in early May to 18 hrs. at the end of June, and thence to about 13 hrs. at end-September.

The tubers were put out in trays to chit in an unheated glasshouse on April 1, 1946. The Sharpe's Express, which sprouted more rapidly, were planted on April 13, and the Gladstone on May 6. Darkening commenced in the short-day sets when the shoots began to show above the soil surface, on May 6 for Sharpe's Express and May 27 for Gladstone.

Observations were made on the following characters: (i) Height of plants, (ii) flowering, (iii) maturity, (iv) tuber weight and number, (v) stolon length and number.

Results

(i) *Height of plants.*—The height of the plants was measured in terms of length of stem; where the leaves arched above the stem tip this latter addition to the height was disregarded. With a branched stem or a plant with more than one stem the length of the longest stem and/or branch was measured. The results are summarized in Table 1.

Gladstone. Under long day the stems of the normal plants did not continue growth after July 30, whilst the bolters continued until Sept. 9. On June 27 the difference in height of plants as between bolter and normal was not statistically significant, indicating that when growth was not slowing down in the normals by the approach of maturity they grew at the same rate as the bolters. On July 30 when the normals had reached full growth of haulm the bolters were significantly taller, whilst it is obvious that on Sept. 24 the bolters were more than twice the height of the normals (43·5 in. as compared with 20·7 in.). Under short day both bolters and normals matured much earlier, and no increase in

height was visible after June 27. There was no significant difference between the two sets of plants under these conditions. The Table shows that the height under short day even with the normal plants was much lower than under long day, but this can probably be accounted for by the 8½-hr. day that this set of plants received. For the present purpose this difference is not important since we are here concerned only with a comparison of normal with bolter under similar conditions, and not with bolter compared with bolter, and normal with normal, under different conditions.

TABLE 1. *Height of Plants*

(*measured in inches to the nearest ½ in.*)

A. LONG DAY

Date		*Gladstone*		*Sharpe's Express*	
		Mean	*S.E.*	*Mean*	*S.E.*
27.6.46	Bolter	15·7	±1·89	22·0	±1·13
	Normal	14·9	±1·24	10·2	±0·31
	Difference	− 0·8*	±2·26	−11·8‡	±1·17
30.7.46	Bolter	33·4	±1·93	33·0	..
	Normal	20·7	±1·58	..	..
	Difference	−12·6‡	±2·50	..‡	..
24.9.46	Bolter	43·5‡	..	..	..

B. SHORT DAY

27.6.46	Bolter	9·5	±0·38	6·2	±0·42
	Normal	9·9	±0·02	6·5	±0·48
	Difference	+ 0·4*	±0·41	+ 0·3*	±0·64

Key to Tables 1–7: * Not significant; † Significant at the 5 per cent. level; ‡ Significant at the 1 per cent. level.

Sharpe's Express. Under long day the normal and bolter plants differ even on June 27, whilst the average height of the bolters (33 in.) on July 30 is very obviously greater, more than three times the height of the normal plants, which did not increase in height after June 27. Under short day, as with Gladstone, the variation in height between bolter and normal was not significant.

(ii) *Flowering.—Gladstone.* There were no flowers in the bolters or normals under short day. This is to be expected since short days of even 12 hrs. greatly depress the tendency of a potato variety to produce flowers in Great Britain [3, pp. 30–3]. Under long day the flowering in the bolters was more abundant than in the normal plants. Nine of the 12 bolter plants were in flower on July 30, whilst only 2 normals were flowering. On Sept. 2 the normals had ceased flowering, though the bolters were all in bloom and were still flowering on Sept. 24.

Sharpe's Express. The bolters and normals did not flower under short day. Under long day the normals produced neither buds nor flowers, whilst the bolters were flowering freely on July 30, though on

June 6 and 27 they were producing buds which dropped off when they were about $\frac{3}{8}$ in. long.

(iii) *Maturity.*—The dates given for harvest in Table 2 are a little earlier than for complete maturity, since it was necessary to take the plants out of the soil when the stolons were not completely decayed and could therefore be fairly easily measured. Full maturity would perhaps have occurred some 7 days later, though in all plants the haulms were beginning to die off at lifting. The one exception to this was the group of Gladstone bolter plants which were lifted on Sept. 27 when they were still green and flowering, since it was feared that if they were left any later they might have been killed by frost and the stolons rendered unfit for measurement. As will be seen later, this factor probably had some effect on the results obtained.

TABLE 2. *Maturity*

		Gladstone			*Sharpe's Express*		
		Planting date	*Harvest date*	*Growth-period in days*	*Planting date*	*Harvest date*	*Growth-period in days*
Long day	Bolter	6.5.46	27.9.46	144	13.4.46	24.9.46	164
	Normal	6.5.46	25.9.46	142	13.4.46	19.7.46	97
Short day	Bolter	6.5.46	4.7.46	59	13.4.46	1.7.46	79
	Normal	6.5.46	4.7.46	59	13.4.46	1.7.46	79

Gladstone. Under short day bolters and normals both matured together and were harvested on July 4. Under long day the normal plants were completely mature on Sept. 25, whilst the bolters, although harvested on Sept. 27, were still green and flowering and would probably have continued some 3 or 4 weeks longer if there had been no risk of frost damage. There was reason to suppose, however, that the growth in length of the stems had ceased by about this date.

Sharpe's Express. Under short day again both bolters and normals matured equally and were harvested on July 1. Under long day the normals were ready for harvesting on July 19, whilst the bolters did not mature until Sept. 24, i.e. over 2 months later than the normals.

(iv) *Tuber weight and number.*—The results for tuber weight and number are given in Tables 3 and 4. The weight was estimated in ounces to the nearest $\frac{1}{4}$ oz. The number of tubers was split into two fractions, large tubers over $\frac{1}{2}$ in. long and small ones of $\frac{1}{2}$ in. or under.

Gladstone. In this variety there was no significant difference between the tuber weight of bolters and normals either under long or short day. However, it is possible that if the bolter had been allowed to reach full maturity under long day in absence of frost, it might have yielded better than the normal if one may judge from the results with Sharpe's Express given below.

In total number of tubers there was also no significant difference

TABLE 3. *Weight of Tubers (in oz.)*

		Gladstone		*Sharpe's Express*	
		Mean	*S.E.*	*Mean*	*S.E.*
Long day	Bolter	28·9	±0·71	44·3	±1·25
	Normal	29·1	±0·69	16·1	±0·90
	Difference	+ 0·2*	±0·94	−28·2‡	±1·54
Short day	Bolter	5·2	±0·54	3·3	±0·67
	Normal	5·8	±0·58	3·6	±0·73
	Difference	+ 0·6*	±0·79	+ 0·3*	±0·99

TABLE 4. *Number of Tubers*

	Variety	*Total number of tubers*				*Large tubers (over ½ in. long)*				*Small tubers (½ in. long or less)*			
		Gladstone		*Sharpe's Express*		*Gladstone*		*Sharpe's Express*		*Gladstone*		*Sharpe's Express*	
		Mean	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*
Long day	Bolter	25·0	±2·0	25·4	±2·4	15·5	±1·05	21·5	±1·68	9·5	±2·05	4·3	±1·09
	Normal	28·9	±2·8	17·9	±1·57	18·6	±1·09	15·5	±1·22	10·3	±2·58	1·8	±0·39
	Difference	+ 3·9*	±3·4	− 7·5†	±2·83	+ 3·1†	±1·46	− 6·0‡	±2·08	+ 0·8*	±3·28	−2·5*	±1·16
Short day	Bolter	21·2	±2·2	9·2	±0·76	16·1	±1·53	7·7	±0·49	5·2	±0·76	1·5	±0·37
	Normal	23·5	±1·4	12·8	±1·3	19·1	±1·39	9·2	±0·74	4·4	±0·66	3·6	±0·67
	Difference	+ 2·3*	±2·6	+ 3·6†	±1·52	+ 3·0*	±2·06	+ 1·5*	±0·89	− 0·8*	±1·01	+2·1†	±0·77

between bolter and normal both under long and short day. However, when we consider the number of tubers over ½ in. long the normals yielded significantly higher than the bolters under long day, whilst under short day there was no difference. There were no significant differences between the bolters and normals either under short or long day in respect of the tubers under ½ in. long.

Sharpe's Express. The results for this variety differ completely from those for Gladstone, since here there is a well-marked difference, significant at the 1 per cent. level, between bolter and normal under long day, *the bolter yielding more than twice the normal.* This agrees with the popular concept of the increased yield of the bolter as compared with the normal. The result was obtained under conditions which allowed the bolter to become completely mature. It is possible that if the bolter had been harvested at the same time as the normal (as was the case with Gladstone) its yield would have been the same or even less, and this point would be well worth investigation. Under short days there is no significant difference between the yields of bolter and normal plants.

Coming to tuber number, we find that in Sharpe's Express there was a difference, significant at the 5 per cent. level, between that of bolter and normal both under long- and short-day conditions. However, whilst under long day the bolter yielded *more* tubers than the normal, under short day the position was reversed and the bolter yielded *fewer* tubers than the normal.

Considering the larger tubers only, the same difference under long day was observed as with the total number, though now more marked, at the 1 per cent. level, i.e. the bolters yielded significantly more large tubers than the normal. Under short day there was no difference between the yields of bolters and normals in respect of number of large tubers.

With the smaller tubers there was a difference, significant at the 5 per cent. level, between normal and bolter under short day only, the normals producing more small tubers than the bolters. This, of course, accounts for the difference in the total number of tubers. In other words, under long day the bolter has more tubers than the normal, and this is made up of the larger tubers, which is also reflected in the increase in tuber weight of the bolters over the normals. Under short day, on the other hand, the normals possess more tubers than the bolters, but as this difference is due only to an increase in the number of smaller tubers, it does not become significant when the weight is considered.

It is evident from the results on tuber weight and number that more work might be done to elucidate some of the more obscure points. It seems probable in any case that the counts of tubers of over ½ in. long may serve as a more reliable guide to the differences between bolter and normal in respect of tuber number where significant differences are seen between bolter and normal in both varieties under long day and none under short. One must not, however, wholly dismiss the possibility that factors other than response to day-length, such as temperature and rainfall, may play a part in conditioning the development of the very smallest tubers right at the end of the season.

(v) *Stolon number and length.*—The number and length of stolons is given in Tables 5 and 6. The number of stolons is obviously very closely connected with the number of tubers, though in practice it is not found to be entirely identical. For example, some small tubers may be borne laterally on stolons which are developing a normal tuber terminally, or they may be sessile on the main stem itself. Since one never (or very rarely) finds completely developed tubers in such positions it must be assumed that such tubers are developed only towards the end of the season (*v.s.*). On the other hand, some stolons, even at maturity, may not have developed tubers, and since at harvest most of the tubers dropped off their stolons when the plants were lifted, the total number of stolons was measured, irrespective of whether they had borne a tuber or not.

In spite of what was stated in the previous paragraph the tuber and stolon numbers agree fairly closely, as will be seen from a comparison of Tables 4 and 5.

Gladstone. There are no significant differences between bolter and normal in respect of stolon number either under long or short day, the same picture being found with the total number of tubers (Table 4).

Sharpe's Express. Here there are significantly more stolons in the bolter than in the normal under long days and no difference under short days. If we compare the latter result with the number of tubers (Table 4) we see that there is some disagreement, since the increased number of tubers (due to an increase in the number of small tubers) on the normals under short day is not reflected by an increase in the number of stolons. The increased number of small tubers must therefore have been produced in the ways suggested above, i.e. laterally on the stolons, or sessilely on the main stems, and this was actually observed when the plants were harvested.

Stolon length can be calculated in two ways, either by obtaining an estimate of the average length of stolons per plant and then subjecting these figures to statistical analysis, or by estimating on a basis of each stolon in the plants under consideration. As Table 6 shows, the results obtained under the two methods of calculation are not the same. When calculating on length of stolons under long day those in the bolters are significantly longer than in the normals, whilst under short days there is no significant difference. This result applies to both varieties. It agrees with practical experience in respect of bolters under long days, namely, that the tubers are produced on longer stolons than in the normal plants of the variety and are hence much more difficult to harvest without injury or loss. Under short days this difference between bolter and normal is eliminated.

When calculating on a basis of average length of stolons per plant the differences are completely eliminated in Sharpe's Express and considerably reduced in Gladstone under long day. Under short day there are no significant differences between bolters and normals in respect of average stolon length in either variety. The differences between the results obtained by the two methods of calculation are to be accounted for as follows: In Sharpe's Express, although the bolter produces longer

TABLE 5. *Number of Stolons per Plant*

		Gladstone		*Sharpe's Express*	
		Mean	*S.E.*	*Mean*	*S.E.*
Long day	Bolter	25·8	±1·85	20·8	±1·07
	Normal	26·7	±1·64	15·1	±0·75
	Difference	+ 0·9*	±2·47	− 5·7†	±1·31
Short day	Bolter	20·6	±1·90	10·1	±0·63
	Normal	23·4	±1·41	9·8	±0·85
	Difference	+ 2·8*	±2·37	− 0·3*	±1·04

TABLE 6. *Length of Stolons*

		Length of stolons (in inches to the nearest ¼ in.)								*Average length of stolons per plant (in inches to the nearest ¼ in.)*			
		Gladstone			*Sharpe's Express*					*Gladstone*		*Sharpe's Express*	
		Longest stolon	*Shortest stolon*	*Mean*	*S.E.*	*Longest stolon*	*Shortest stolon*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*
Long day	Bolter	32¼	¾	5·76	±0·26	8¼	¾	2·55	±0·054	5·35	±0·72	2·68	±0·176
	Normal	7¾	¼	3·14	±0·08	5	¼	1·72	±0·065	3·67	±0·15	1·73	±0·131
	Difference	..	..	−2·62†	±0·29	..	..	−0·83†	±0·089	−1·68†	±0·74	−0·95*	±0·217
Short day	Bolter	3¾	¼	1·68	±0·15	3	¼	0·90	±0·054	1·69	±0·13	0·89	±0·06
	Normal	4¼	¼	2·02	±0·05	2	¼	0·93	±0·057	1·93	±0·12	0·93	±0·09
	Difference	..	..	+0·34*	±0·28	..	..	+0·03*	±0·081	+0·24*	±0·18	−0·04*	±1·02

stolons than the normal under long day it also produces *more shorter stolons*, and these cancel out the effect of the long stolons when the averages are taken. With Gladstone, however, the stolon number is the same in bolter and normal under long day, and the effect of the longer bolter stolons is not therefore obscured by a greater number of shorter ones when the average per plant is considered.

TABLE 7. *Summary of Comparisons between Bolter and Normal under Long- and Short-Day Conditions*

	Gladstone		*Sharpe's Express*	
	Long day	*Short day*	*Long day*	*Short day*
Height of plants on 27.6.46	*	*	‡ B>N	*
,, ,, 30.7.46	‡ B>N	..	‡ B>N	..
,, ,, 24.9.46	‡ B>N	..	..	..
Amount of flowering	B>N	None	B>N	None
Matured at	?	Same time	B later than N	Same time
Weight of tubers	*	*	‡ B>N	*
Total number of tubers	*	*	† B>N	† N>B
Number of large tubers	† N>B	*	‡ B>N	*
,, small ,,	*	*	*	† N>B
Number of stolons per plant	*	*	‡ B>N	*
Length of stolons	‡ B>N	*	‡ B>N	*
Average length of stolons per plant	† B>N	*	*	*

Key: B>N Bolter did better than normal; N>B Normal did better than bolter.

Discussion

A summary of the results obtained is shown in Table 7. Apart from certain exceptions the bolter plants differed from the normals under long day-length, whilst under short day these differences were completely effaced. This was shown in both varieties by such features as height of plant, flowering, maturity, and length of stolons. However, with features such as weight of tubers, total number of tubers, number of large and small tubers, number of stolons, and average length of stolons per plant the two varieties did not present similar results.

The first-early variety, Sharpe's Express, whose bolter plants under long day were allowed to reach full maturity, showed an increase under long day of bolter over normal in tuber weight and number of stolons per plant that was effaced under short day. With Gladstone, however, probably because the bolter plants were harvested in an immature state, these features did not differ either under long or short day.

There was also no significant difference under long or short day in the total number of tubers with Gladstone, though the normals had more larger tubers (significant at the 5 per cent. level) than the bolters. Under long day the bolters in Sharpe's Express outdid the normals, and under short day the normals outdid the bolters in tuber number. On splitting tuber number into two groups of over and under $\frac{1}{2}$-in. tubers, we find that the increase under long day of bolters over normals is due

to an increase in the number of large tubers; whilst under short day it is due to an increase in the number of small tubers.

The rather varied results in the two varieties in respect of tuber number point to a need for further experimentation.

Apart from the tuber number results it is quite evident that short day has the effect of effacing the most obvious differences between bolter and normal plants, especially in respect of height of plants, maturity, and length of stolons. In the fully matured bolter plants of Sharpe's Express the effect of the short day was to efface the increase in yield of bolter over normal that is seen under long day.

The results of the present experiments bear out the conclusions tentatively put forward by the writer in an earlier publication [2], namely, that the bolter differs from the normal in respect of its photoperiodic response. It would appear to be a mutation back to the presumably more primitive or ancestral short day photoperiodic reaction of the potatoes from the S. American Andes, and seems, therefore, to afford additional evidence for the Andean origin of our domestic potato varieties.

The precise nature of the mutation yet remains to be seen. Thomas [4] has suggested that it may be due to the gain of a chromosome or fragment, though this idea was not corroborated by Carson and Howard [1].

At all events, the findings of the experiments outlined in the present paper throw some light on the nature of the mechanism involved in the bolter phenomenon. It is to be hoped that future investigations both in the realms of photoperiodism and cytology may provide us with more complete knowledge and point a way to its eventual control.

Summary

The well-known differences between bolter and normal strains of the two potato varieties Gladstone and Sharpe's Express were shown to be well pronounced, especially in the latter variety. Under long days the bolter plants were significantly taller, matured earlier, flowered more freely, and had longer stolons than the normals. Under short days these differences were completely effaced.

When the bolter plants of Sharpe's Express under long day were allowed to reach full maturity they possessed a larger number of tubers than the normals, though this position was reversed under short days by reason of a greater number of tubers of $\frac{1}{2}$ in. long and under.

The bolters of Sharpe's Express possessed a greater weight of tubers and a larger number of stolons per plant than the normals under long days. These differences were completely removed under short days.

The results obtained show that the bolter when grown under short days is indistinguishable in most of its features from the normal, thus lending weight to the hypothesis that the change from normal to bolter is due to a mutation of one or more relatively unstable genes controlling response to day-length.

According to this view the bolter is a reversion to the more ancestral type of short-day adapted potato such as is found under cultivation in

the S. American Andes and from which our own domestic potatoe were probably derived.

Acknowledgements.—My thanks are due to Dr. T. McIntosh fo kindly supplying the material, and to Dr. J. Wishart and Mr. G Morgenstern for the statistical analysis of the results.

REFERENCES

1. G. P. Carson and H. W. Howard, 1944, Nature, **154,** 829.
2. J. G. Hawkes, 1944, ibid., **157,** 375.
3. C. M. Driver and J. G. Hawkes, Imp. Bur. Pl. Breed. & Gen., Cambridge, 1943.
4. P. T. Thomas, 1945, Nature, **155,** 242.

(*Received June 18, 1947*)

FIG. 1. Gladstone normal in the foreground and bolter in the middle distance.

FIG. 2. View of the darkening-boxes for giving short days to normal and bolter plants of the two varieties. The plants in the nearest box are Gladstone normals.

FIG. 3. Darkening-box showing Sharpe's Express normal plants just before maturity. The slight curling of the leaves is not due to leaf-roll virus but probably to the plants being near maturity.

PRELIMINARY EXPERIMENTS ON THE PROTECTION OF CUT SETS OF POTATO FROM INFECTION WITH PENICILLIUM

JANE BROADFOOT
(*Formerly of the West of Scotland Agricultural College*)

DURING the war seed potatoes were urgently needed in Algiers, Malta, Cyprus, and Palestine. As transport was scarce, Mr. W. Gray of the Ministry of Food, in collaboration with the Ministry of War Transport, tried the method of cutting single-eye sets, originally developed in Russia [1, 2]. In 1942 there was no trouble with mould, but in 1943 each lot of cut sets was heavily contaminated with Penicillium and advice was asked of the West of Scotland Agricultural College. As it was hoped that the export of cut sets might be developed on a large scale, the experiments described in the present paper were undertaken in an attempt to solve the problem. They were designed to study methods of inducing a protective cork layer on the cut surface, and the effects of various antiseptics under different conditions. A small planting trial was carried out to demonstrate the effect of the treatments on yield. Other treated sets were shipped to the Middle East, and reports were received of their condition when they arrived there.

Methods used.—When the work was begun at the Ministry of Food office, great trouble was taken over sterilization, but when the investigation started it was decided that conditions must be as similar as possible to those which would be used in commercial practice, no attempt being made to sterilize tubers, knife, benches, or atmosphere. Sets were cut with a circular scoop which produced a set about 1 in. in diameter on the skin surface, with an eye in the centre, and about ½ in. deep at the thickest part of the flesh. They were laid on the benches in a single layer, cut surface up.

The varieties used were supplied by the Ministry of Food and varied according to their availability, but were confined to Kerr's Pink, Up to Date, and Epicure, these being most in demand in the Middle East, and Doon Star and Golden Wonder, which were used for experiment because of the former's susceptibility to dry rot and the latter's resistance to blight. Only sound tubers were cut. The fungicidal substances used were usually in powder form and dusted on to the cut surface. Volatile substances like thymol were carried on powdered peat: 15 gm. thymol to 85 gm. peat treated in a closed tin for 2 to 3 hrs. at 150°–180° C. This method was devised by Dr. R. Tompkins, Low Temperature Station, Cambridge, and suggested to me by Dr. C. E. Foister, Plant Pathologist to the Department of Agriculture for Scotland. Boric acid was used as a 5 per cent. aqueous solution and the sets were dipped in it at 21° C. For inducing suberization of the cut surface a covered sink at 6° C., and later an incubator at 20° C. and a germinator at 21°–26° C., were used. The temperature in the laboratory usually varied between 7° and 10° C. Suberization usually took about 7–8 days.

As the Middle East countries concerned have planting seasons differing from Great Britain, in some cases having two in the year, and as shipping was then uncertain and the sets might have to be stored for considerable periods before dispatch, cutting could not be restricted to any one season.

Laboratory Tests

Experiment 1.—Doon Star, Epicure, Kerr's Pink, and Up to Date were cut into sets, half of each variety being placed in the sink and half on the benches. A week later half of the sets in the sink and on the benches were treated with boric acid solution, and after a further week half of each lot was treated with a light covering of peat impregnated with thymol. At this time the untreated Epicure and Doon Star sets showed signs of mould, which gradually increased until the cut surface was covered with Penicillium. After 97 days the controls were very mouldy and dry. Those treated with boric acid, after being in the sink, were fairly mouldy and very dry, and those treated with boric acid only had no mould. The thymol-treated sets were not mouldy but dried out rapidly and were apparently dead. Table 1 shows these results, excluding those of thymol treatment.

TABLE 1. *Treatment of Cut Sets in Moist Atmosphere alone and in Boric Acid Solution*

Variety (cut 10.12.43)	*Treatment 21.12.43*	*No. of sets*	*Mouldy after 3 months (27.3.44) per cent.*
Doon Star	Laboratory benches	26	88
Epicure	,, ,,	23	87
Kerr's Pink	,, ,,	22	77
Up to Date	,, ,,	21	81
Doon Star	Moist atmosphere	27	0
Epicure	,, ,,	26	0
Kerr's Pink	,, ,,	17	29
Up to Date	,, ,,	20	10
Doon Star	Lab. benches, boric acid	26	0
Epicure	,, ,, ,, ,,	23	0
Kerr's Pink	,, ,, ,, ,,	19	0
Up to Date	,, ,, ,, ,,	20	0
Doon Star	Moist atmosphere, boric acid	26	77
Epicure	,, ,, ,, ,,	21	84
Kerr's Pink	,, ,, ,, ,,	15	40
Up to Date	,, ,, ,, ,,	18	67

This set of tests was not repeated, but the fact that sets treated in a moist atmosphere alone had no mould or only a small amount compared with the control seemed to indicate that a good cork layer on the surface was the first requisite.

Experiment 2.—Doon Star and Kerr's Pink tubers were cut and 50 sets of each placed in the incubator, in a germinator, and on the bench. On the eighth day the sets from the incubator and germinator were much

better suberized than the controls on the bench, being firm, with a skin which could be cracked on slight pressure. The suberization of the sets in the germinator was considerably better than in those from the incubator, but the bacterial rot and mouldiness that also developed showed that the humidity must be carefully controlled.

It was thought that better suberization would protect the sets from damage by thymol and two types of thymol-treatment were tried.

Peat impregnated with thymol was used, as in the previous experiment, but as it was expected that the peat might fall through the slats of the boxes to be used for transport and thus cease to maintain contact with the sets, a second group was sprayed with a 15 per cent. solution of thymol in 95 per cent. alcohol in an attempt to obviate this difficulty. The results are shown in Table 2.

TABLE 2. *Suberized Sets treated with Thymol*

Variety (cut 10.1.44)	*Treatment 10.1.44*	*No. of sets*	*Mouldy after 77 days 27.3.44 per cent.*	*Remarks*
Kerr's Pink	Incubator control	16	0	(6 per cent. Penicillium in eye; 6 per cent. dry rot)
Doon Star	,, ,,	16	0	(44 per cent. dry rot) living
Kerr's Pink	Germinator control	16	25	..
Doon Star	,, ,,	16	38	(44 per cent. dry rot) living
Kerr's Pink	Bench control	16	85	..
Doon Star	,, ,,	16	100	Living
Kerr's Pink	Incubator, thymol in alcohol spray	17	0	..
Doon Star	,, ,,	17	0	(71 per cent. dry rot) dead
Kerr's Pink	Germinator, thymol in alcohol spray	17	24	(Some dry rot) dead
Doon Star	,, ,,	14	21	(Some dry rot)
Kerr's Pink	Bench, thymol in alcohol spray	17	0	Dead
Doon Star	,, ,,	17	0	..
Kerr's Pink	Incubator, thymol in peat	17	0	..
Doon Star	,, ,,	17	0	(Some dry rot) living
Kerr's Pink	Germinator, thymol in peat	17	0	..
Doon Star	,, ,,	17	6	(35 per cent. dry rot) living
Kerr's Pink	Bench, thymol in peat	17	0	..
Doon Star	,, ,,	17	0	Dead

It is clear that although suberization was better under wet conditions in the germinator, subsequent protection from mould was not so good as when suberization took place under dry conditions in the incubator, but in both the protection was better than where only slight suberization took place on the benches. Disinfection by the thymol-impregnated

peat appears to be rather better than with the thymol-alcohol spray, and the latter caused the tissues to die more rapidly. No mould developed in the incubator control sets, again suggesting that if a good cork layer is formed, disinfection may be unnecessary. After 10 weeks most of the sets without thymol treatment, or treated with thymol in peat after either dry or wet suberization, had some at least of the buds apparently alive. Those treated by the alcohol method and the control (bench) sets treated with thymol in peat had no live buds. Suberization, therefore, apparently had a beneficial effect, both in protecting the set from mould and, to some extent, from the harmful effect of the disinfectant.

Experiment 3.—Epicure and Up to Date sets were suberized in the incubator with a bench control. No disinfectants were used. Table 3 shows the state of mouldiness after 66 days.

TABLE 3

Variety (cut 27.1.44)	*Treatment*	*No. of sets*	*Mouldy 27.3.44 per cent.*	
Epicure . .	Incubator	100	0	(6 mouldy on uncut surface; 14 mouldy in eye)
Up to Date . .	,,	100	2	(13 mouldy on uncut surface; 9 mouldy in eye)
Epicure . .	Bench	100	6	(50 mouldy on uncut surface; 0 mouldy in eye)
Up to Date . .	,,	100	3	(98 mouldy on uncut surface; 0 mouldy in eye)

The untreated sets in this trial did not dry out nearly so quickly as those cut previously. This may have been due either to a period when the temperature of the laboratory rose to about 15·6° C. during weekdays for about a fortnight, inducing a certain amount of belated suberization, or to the difference in variety or in state of dormancy allowing the outer tissues to suberize more readily at low temperatures. The same consideration may account for the very small percentage of mould on the bench lots. The difference in dryness between the two lots 198 days after cutting was more perceptible, as shown in Table 4, 20 sets of each lot of Epicure having been removed for planting.

TABLE 4

Variety (cut 27.1.44)	*Treatment*	*No. of sets*	*Bearing live sprouts 14.8.44 per cent.*
Epicure . . .	Incubator	80	79
Up to Date . .	,,	100	95
Epicure . . .	Bench	80	30
Up to Date . .	,,	100	23

Sprouts were considerably larger and stronger in the incubator lots than in the bench lots. Suberization in the bench lots, however, was sufficiently good to have prevented any further mould.

Experiment 4.—Kerr's Pink sets without suberization were treated on the cut surface in lots of 33 with zinc oxide, Ceresan, peat impregnated with diphenyl, and an aqueous suspension of zinc oxide, respectively. One lot was placed cut-surface downwards on wet sand, and one under a damp sack, both at room-temperature, and one lot was kept on the bench as control.

Kerr's Pink sets suberized in the incubator were treated in lots of 33 with the same substances except with zinc oxide suspension.

The state of mouldiness in these sets after 31 days is shown in Table 5.

TABLE 5. *Suberized and Unsuberized Sets treated with Various Substances*

Variety (cut 26.2.44)	*Treatment*	*No.*	*Mouldy after 31 days per cent.*
Kerr's Pink	Zinc oxide powder	33	82
,,	Ceresan	33	64 (edges)
,,	Diphenyl-peat	33	36
,,	Zinc oxide suspension	33	61
,,	Control	33	45
,,	Wet sand	33	82
,,	Wet sack	33	25
,,	Incubator, zinc oxide powder	33	0
,,	Incubator, Ceresan	33	0
,,	Incubator, diphenyl-peat	33	0
,,	Incubator control	27	0 (33 per cent. slightly mouldy round *uncut* surface edge)

This seems to show that the protective substances used do not have complete control over mould in the absence of suberization, and that if suberization is adequate there is little advantage in using any of them. Zinc oxide powder and the wet-sand treatment gave the least degree of protection. Again there was more sign of life in the buds of the suberized eyes.

Planting Trials

To obtain some idea of the effect of these treatments on the subsequent growth of the sets, a small plot was planted with selected lots. One early and one maincrop variety only were planted, viz. Epicure and Kerr's Pink. Some of the sets, particularly those cut in December 1943, showed no external sign of life at planting time; 20 sets of each lot were planted on March 30, 1944, 3 to 4 in. deep, 12 in. apart in drills 21 in. apart. There was a small amount of leaf roll and blight in the growing crop, which was lifted on Oct. 4. The results are shown in Table 6.

In Epicure, the suberized sets (drill 3) gave considerably better growth and yield than the non-suberized (drill 4), and the cut sets gave a much inferior yield compared with the control (drill 5). In Kerr's

TABLE 6. *Results of Planting Treated Sets*

Drill	*Variety*	*Treatment and Date of Cutting*	*No. of sets*	*Plants grown per cent.*	*Tubers produced lb.*	*Weight of tubers produced as per cent. of control*
1	Epicure	Bench 10.12.43	20	0	..	..
2	,,	,, 10.12.43 thymol-peat	20	0	..	..
3	,,	Incubator 27.1.44	20	95	36	49
4	,,	Bench 27.1.44	20	80	19	26
5	,,	Whole tubers	20	100	74	100
6	Kerr's Pink	Bench 10.12.43	20	0	..	..
7	,,	,, 10.12.43 thymol-peat	20	0	..	..
8	,,	Ceresan 26.2.44	20	0	..	..
9	,,	Zinc oxide powder 26.2.44	20	0	..	..
10	,,	Diphenyl 29.2.44	20	0	..	..
11	,,	Control 26.2.44	20	0	..	..
12	,,	Incubator 4.3.44 zinc oxide	20	15	11	22
13	,,	,, 4.3.44 diphenyl-peat	20	15	10	20
14	,,	,, 4.3.44 Ceresan	20	30	19	39
15	,,	,, 4.3.44 control	20	20	10	20
16	,,	,, 4.3.44 Penicillium in eye	20	36	14	29
17	,,	,, 18.1.44 thymol-peat	20	88	41	84
18	,,	,, 18.1.44 thymol-alcohol	20	25	9	18
19	,,	Bench 18.1.44 thymol-alcohol	20	0	..	..
20	,,	,, 18.1.44 control	20	0	..	..
21	,,	Incubator 18.1.44 control	20	75	37	76
22	,,	Whole tubers	20	100	49	100

Pink all the non-suberized sets failed completely, even those (drill 20) cut only 10 days before the Epicure sets (drill 4) which made fair growth. Drill 21 cut on Jan. 18, 1944, made better showing than drill 15 cut on March 4, 1944, and undergoing the same treatment. This again suggests that the state of dormancy of the tuber may affect the viability of sets cut at different times.

In Kerr's Pink also the suberized sets treated with zinc oxide powder, diphenyl-peat, Ceresan and thymol-peat, drills 12, 13, 14, and 17, gave equal or better yield than their controls, drills 15 and 21, indicating that although the use of these substances gave no advantage over suberization alone in the control of mould, their use might have some effect in producing a better yield than that from untreated sets. Suberized sets with Penicillium infection in the eye (drill 16) gave better yield than clean suberized sets of the control (drill 15), contrary to what might have been expected.

Transport Trials

About 500 single-eye sets and 200 rose-end slices of Up to Date, which had been cut by casual labour at the Ministry of Food and stored untreated for about a week, were sent to Palestine and Cyprus in Jan. 1944, packed in a wooden case with thymol-peat sprinkled over the sets and placed among the sets in small muslin bags. These sets arrived at their destination 40–4 days later, when it was reported back that the single-eye sets were 76 per cent. and the rose-end sets 60 per cent. in 'good condition', the remainder being useless for various reasons, e.g. sprouts being rubbed off, sets dried out. No information was given as to the mouldiness among the useless sets. The sets were distributed to various centres for planting, although in Cyprus the planting season was

nearly over, but no information has been received since as to the results of planting.

Golden Wonder and Epicure sets cut in the laboratory in April 1944 were sent to Algiers on May 2, 1944. Some of the sets were suberized in the incubator for 7 days at 21° C. and some were untreated. They were packed with or without thymol in peat scattered over the sets or in bags. These arrived in Algiers 52 days after cutting and a report was received of their condition on arrival. The condition, apart from mouldiness, varied from 'stunted', 'fairly dry', to 'very dry'. The name of the mould was not given.

About 20 sets each of these lots had been kept in Glasgow as controls, and on June 20, 1944, about 67 days after cutting, their state of mouldiness with Penicillium was noted, together with the results reported from Algiers (Table 7).

TABLE 7. *Report on Sets shipped to the Middle East*

Variety (cut 14.4.44)	*Code no.*	*Treatment (14.4.44)*	*Condition before dispatch (2.5.44)*	*Condition on arrival (5.6.44)*	*Condition of control kept in Glasgow (20.6.44)*
Golden Wonder	1	Incubator, thymol-peat scattered	Not mouldy	12 per cent. mouldy, 73 per cent. germinated	..
„	3	Bench, thymol-peat in bag	Very mouldy	Slightly mouldy, 12 per cent. germinated	..
„	5	Incubator control	Not mouldy	7 per cent. mouldy, 78 per cent. germinated	12 per cent. mouldy, 50 per cent. sprouted
„	7	Bench control	Fairly mouldy	Sound, 98 per cent. germinated	66 per cent. mouldy, no sprouts
Epicure	2	Bench thymol-peat	Slightly mouldy	Mouldy, bad condition, 30 per cent. germinated	..
„	4	Incubator thymol-peat bag	Not mouldy	4 per cent. mouldy, 84 per cent. germinated	..
„	6	Incubator control	Not mouldy	4 per cent. mouldy, 80 per cent. germinated	Not mouldy, 55 per cent. sprouted but drying out
	8	Bench control	Very mouldy	6 per cent. mouldy, 78 per cent. germinated	89 per cent. very mouldy, some sprouts drying out

The condition of the sets on arrival bears little or no relation to the condition on dispatch or to the condition of the sets kept behind. Two lots, Golden Wonder 3 and Epicure 8, which left in a very mouldy condition, i.e. at least over 80 per cent. mouldy, arrived with very little and 6 per cent. mouldiness respectively. The thymol treatment appears to have served no purpose and the suberization had done little good, the lot arriving in the best condition being Golden Wonder 7 which was untreated. These sets were planted on June 12, 1944, which was very late for the summer planting but no report was received of the results of planting.

On Aug. 14, 1944, 121 days after cutting, there was no perceptible difference in the state of dryness of the bench and incubator lots of Epicure and Golden Wonder cut on April 14, 1944. This is opposed to the results shown in Table 4, where the difference in drying out of

bench and incubator lots of Epicure and Up to Date was still quite well marked on Aug. 14, 1944.

Discussion

Although the trials detailed above are purely preliminary, it appears on the whole that the use of fungicidal substances is unnecessary for preserving cut potato sets when properly stored, provided a good cork layer has been induced, and the storage temperature is around 4° C. This is similar to the method used in Canada [3], where excised eyes intended for air transport to inaccessible regions were kept for a week at about 24° C. and stored at about 4° C. until shipped. This method could probably be adapted to large-scale operations, using thermostatic controls in an atmosphere with controlled humidity, i.e. the humidity during cork formation would have to be higher than during storage. The storage temperature as well as preventing mould on the cork layer would also prevent too much premature sprouting.

Thermostatic and humidity controls in the holds of ships used for transporting the sets would ensure the arrival of the sets in good condition. In periods of emergency, however, conditions might be unsuitable for the preservation of the cut surface, owing to high temperature, excessive humidity, or bad ventilation, and in that case the use of a fungicide might be advantageous, but from the trials it does not appear which, if any, of those tried is the most suitable. Transport trials under varying conditions still need to be carried out to clear up this point.

Thymol in peat is an effective fungicide under laboratory conditions, although not always under transport conditions (Table 7), but is harmful to the tuber. Foister [4] also found this to be the case when trying it for the control of dry rot. Diphenyl in peat, boric acid, organo-mercuric compounds and zinc oxide may all have possibilities, although in the trials none inhibited Penicillium under all conditions. Except in the case of boric acid, a good cork layer has to be induced before disinfection is adequate.

Bald [5] recommends that cut sets should be kept at 70° F. for one week in wet sand sprinkled with zinc oxide to keep them clean, or cut and dipped in a suspension of zinc oxide immediately before planting. Dillon Weston and Taylor [6] in working on the development of Penicillium on cut vegetable surfaces found that its growth on cut potato was encouraged by 2½ per cent. solutions of copper, nickel, and ferrous salts, but that it was inhibited by the heavier salts, e.g. those of mercury and copper sulphate in 1 per cent. solution. Dr. Dillon Weston communicated that if sets were dipped in water and kept under a moist sack he had no trouble with Penicillium, and that he found zinc oxide the most suitable chemical treatment for the cut surface. Zinc oxide, and wet sand or sacks were not successful as treatments in the present case.

Priestly and Woffenden [7] found that healing of the cut surface of potato sets and the yield therefrom varied a good deal with the variety and the conditions under which the sets were kept after cutting, e.g. healing by means of a cork layer did not occur if the sets were exposed

to sunlight or in too dry an atmosphere. This may explain some of the inconsistencies in the present work where five varieties were used.

The question of different reactions of the tuber to cutting at different stages of dormancy, as suggested by Bell *et al.* [8], needs further investigation, as does the question of whether tubers should be sprouted or not before cutting.

From the results of the planting trials, it is obvious that sets of between ¼ and ½ oz. cannot compete for yield with whole tubers under West of Scotland conditions, and the labour involved in cutting would also be against the use of small cut sets, except in time of emergency, as already suggested by McDermott [9] and Polunin [10], or for transit to inaccessible places, but should such an emergency again arise, various methods of disinfection might be worth investigation.

The information received from the Middle East was not sufficient to gain any idea of the effect which the condition of the sets on arrival would have on their subsequent yield.

The fact that in one trial the single-eye sets travelled better than the rose-end slices, both lots being unsuberized, indicates that a spherical cut surface may have a less harmful effect on the set than the relatively large flat surface of a thin slice. On the other hand, the absence of information as to their respective yields means that no true comparison can be made between the two methods of cutting. This difficulty of communication between home and overseas workers would probably not arise under peace-time conditions.

It appears that, to avoid some at least of the wastage during storage and transport, varieties susceptible to dry rot, such as Doon Star, should be avoided, and only sound sets exported.

Summary

Preliminary trials were carried out on methods of protecting small single-eye cut sets of potato from contamination by Penicillium during lengthy periods in storage and transport.

These trials included treatment with 5 per cent. boric acid solution, thymol- and diphenyl-impregnated peat, zinc oxide, Ceresan, and all were effective if a good cork layer had been induced on the cut surface.

Adequate suberization was found to be effective without the use of a fungicide, and also prevented the sets from drying out provided the storage temperature was controlled.

Reports on the condition of sets after transport tend to conflict with the condition of controls, indicating that more work is required on this part of the problem.

Acknowledgements.—Thanks are extended to Mr. W. Gray, who began the work, supplied material for its continuation, and arranged for transport to the Middle East; to Dr. C. E. Foister, for helpful suggestions; and to Prof. K. W. Braid for his interest and help throughout the work.

bench and incubator lots of Epicure and Up to Date was still quite well marked on Aug. 14, 1944.

Discussion

Although the trials detailed above are purely preliminary, it appears on the whole that the use of fungicidal substances is unnecessary for preserving cut potato sets when properly stored, provided a good cork layer has been induced, and the storage temperature is around 4° C. This is similar to the method used in Canada [3], where excised eyes intended for air transport to inaccessible regions were kept for a week at about 24° C. and stored at about 4° C. until shipped. This method could probably be adapted to large-scale operations, using thermostatic controls in an atmosphere with controlled humidity, i.e. the humidity during cork formation would have to be higher than during storage. The storage temperature as well as preventing mould on the cork layer would also prevent too much premature sprouting.

Thermostatic and humidity controls in the holds of ships used for transporting the sets would ensure the arrival of the sets in good condition. In periods of emergency, however, conditions might be unsuitable for the preservation of the cut surface, owing to high temperature, excessive humidity, or bad ventilation, and in that case the use of a fungicide might be advantageous, but from the trials it does not appear which, if any, of those tried is the most suitable. Transport trials under varying conditions still need to be carried out to clear up this point.

Thymol in peat is an effective fungicide under laboratory conditions, although not always under transport conditions (Table 7), but is harmful to the tuber. Foister [4] also found this to be the case when trying it for the control of dry rot. Diphenyl in peat, boric acid, organo-mercuric compounds and zinc oxide may all have possibilities, although in the trials none inhibited Penicillium under all conditions. Except in the case of boric acid, a good cork layer has to be induced before disinfection is adequate.

Bald [5] recommends that cut sets should be kept at 70° F. for one week in wet sand sprinkled with zinc oxide to keep them clean, or cut and dipped in a suspension of zinc oxide immediately before planting. Dillon Weston and Taylor [6] in working on the development of Penicillium on cut vegetable surfaces found that its growth on cut potato was encouraged by 2½ per cent. solutions of copper, nickel, and ferrous salts, but that it was inhibited by the heavier salts, e.g. those of mercury and copper sulphate in 1 per cent. solution. Dr. Dillon Weston communicated that if sets were dipped in water and kept under a moist sack he had no trouble with Penicillium, and that he found zinc oxide the most suitable chemical treatment for the cut surface. Zinc oxide, and wet sand or sacks were not successful as treatments in the present case.

Priestly and Woffenden [7] found that healing of the cut surface of potato sets and the yield therefrom varied a good deal with the variety and the conditions under which the sets were kept after cutting, e.g. healing by means of a cork layer did not occur if the sets were exposed

to sunlight or in too dry an atmosphere. This may explain some of the inconsistencies in the present work where five varieties were used.

The question of different reactions of the tuber to cutting at different stages of dormancy, as suggested by Bell *et al.* [8], needs further investigation, as does the question of whether tubers should be sprouted or not before cutting.

From the results of the planting trials, it is obvious that sets of between $\frac{1}{4}$ and $\frac{1}{2}$ oz. cannot compete for yield with whole tubers under West of Scotland conditions, and the labour involved in cutting would also be against the use of small cut sets, except in time of emergency, as already suggested by McDermott [9] and Polunin [10], or for transit to inaccessible places, but should such an emergency again arise, various methods of disinfection might be worth investigation.

The information received from the Middle East was not sufficient to gain any idea of the effect which the condition of the sets on arrival would have on their subsequent yield.

The fact that in one trial the single-eye sets travelled better than the rose-end slices, both lots being unsuberized, indicates that a spherical cut surface may have a less harmful effect on the set than the relatively large flat surface of a thin slice. On the other hand, the absence of information as to their respective yields means that no true comparison can be made between the two methods of cutting. This difficulty of communication between home and overseas workers would probably not arise under peace-time conditions.

It appears that, to avoid some at least of the wastage during storage and transport, varieties susceptible to dry rot, such as Doon Star, should be avoided, and only sound sets exported.

Summary

Preliminary trials were carried out on methods of protecting small single-eye cut sets of potato from contamination by Penicillium during lengthy periods in storage and transport.

These trials included treatment with 5 per cent. boric acid solution, thymol- and diphenyl-impregnated peat, zinc oxide, Ceresan, and all were effective if a good cork layer had been induced on the cut surface.

Adequate suberization was found to be effective without the use of a fungicide, and also prevented the sets from drying out provided the storage temperature was controlled.

Reports on the condition of sets after transport tend to conflict with the condition of controls, indicating that more work is required on this part of the problem.

Acknowledgements.—Thanks are extended to Mr. W. Gray, who began the work, supplied material for its continuation, and arranged for transport to the Middle East; to Dr. C. E. Foister, for helpful suggestions; and to Prof. K. W. Braid for his interest and help throughout the work.

REFERENCES

[1]1. T. D. LYSENKO, Proc. Lenin Acad. Agric. Sci. U.S.S.R., 1942, Nos. 9–10, 3–6.
2. —— Nature, 1942, **150,** 456.
[1]3. Can. Dept. Agric., Central Exptl. Farm, Ottawa.
4. C. E. FOISTER, Nature, 1945, **156,** 394.
5. T. G. BALD, Austral. Inst. Agric. Sci., 1943, **9,** 35; Rev. Appl. Myc., 1943, **22,** 370.
6. W. A. R. DILLON WESTON and R. C. TAYLOR, Nature, 1943, **151,** 54.
7. J. H. PRIESTLY and L. M. WOFFENDEN, Ann. Appl. Biol., 1923, **10,** 96–115.
8. G. D. H. BELL, M. R. GIBSON, and W. A. R. DILLON WESTON, J. Agric. Sci., 1942, **32,** 255.
9. N. MCDERMOTT, Agriculture, 1945, **52,** 11.
10. N. POLUNIN, Gard. Chron., Jan. 1943, p. 36.

[1] Owing to inaccessibility of the originals, these references have not been checked. They were supplied with abstracts by scientific workers to Mr. W. Gray when he began the work.

(*Received February 13, 1947*)

THE ASH COMPONENTS OF SOME MOORLAND PLANTS

BRYNMOR THOMAS AND N. TRINDER
(*King's College, Newcastle-upon-Tyne*)

Introduction.—It has already been established [1] that the edible foliage of common heather (*Calluna vulgaris*) is more highly efficient in respect of certain of its ash components than is lowland grass of good quality. That the same superiority would be found in comparing heather with the herbage of 'white' land, i.e. fell land carrying an essentially grassy sward, is by no means certain, although the authors have implied such superiority by their suggestion that the efficacy of the 'heather change' for sheep suffering from the deficiency disease 'Border pine' is due to the increased supplies of iron, manganese, and cobalt [1]. The uptake of some trace elements is undoubtedly affected by soil reaction, and the soil conditions on a 'white' fell are not necessarily different from those on an adjoining heather moor. It is, however, improbable that soil reaction is decisive in determining uptake. Such evidence as exists points to differential absorption by species as the major factor.

It is doubtful whether any one of the moorland plants examined in our investigation occurs exclusively on 'white' land; a majority is certainly common to both. Nevertheless, these plants must be regarded primarily as components of the grassy fell sward. White bent (*Nardus stricta*) is perhaps exceptional, since it may so dominate the sward that it swamps the influence of other species. The remaining species, with the possible exception of flying bent (*Molinia coerulea*), seldom occupy large areas to the virtual exclusion of almost all others. At first sight, therefore, it may appear improbable that any one species, providing only a relatively small proportion of the feed to be derived from a mixed sward, can exert a considerable effect on the mineral content of that sward as a whole. It should be remembered, however, that as the sheep is such a highly selective grazer, its diet might include a particular plant in amounts quite disproportionate to the area covered by the species. Concentration of this kind almost certainly occurs with some of the major ash components, for draw-moss (*Eriophorum vaginatum*), as one of us has shown [2], may owe its exceptional value as a spring food for hill sheep to the large amount of phosphorus contained in the leaf-butt. Deficiencies of calcium and phosphorus severe enough to cause easily recognizable bone dystrophies seldom occur in this country, but it is highly probable that such deficiencies do affect productivity. On hill pastures, in particular, the limiting factor to productivity is as likely to be a deficiency of one or both of these elements as is a lack of protein. Hence, the major ash components, no less than the trace elements, contained in the more important moorland plants, merit close consideration. Singularly little information on the former is available, and practically nothing is known of the latter.

Experimental technique.—Samples of flying bent, deer-hair (*Scirpus caespitosus*), and blaeberry (*Vaccinium myrtillus*) were obtained from

the Smale forest in the valley of the North Tyne, an area recently planted with conifers by the Forestry Commission, and white bent, stool bent (*Juncus squarrosus*), and draw-moss from the hill farm of Newbiggin, at Blanchland in south Northumberland. The soil and topography of both sites have been described elsewhere [3].

Draw-moss was sampled by hand, the material being, in fact, drawn in small tufts. Samples of all other species were taken by cutting within an inch of ground level with heavy scissors. Subsequently the samples were air-dried and ground in a power mill to pass a $\frac{1}{32}$-in. screen. The April and May samples of white bent and flying bent contained some of the previous season's growth, and had to be sorted before drying. The 'scallions' of draw-moss were cut off immediately on arrival, and the foliage and green stem of blaeberry picked while still fresh. Possible contamination arising from the use of a mill was envisaged, but as the investigation was concerned essentially with comparative values it was considered permissible to ignore it. The analytical methods employed have already been described by the authors [1].

Experimental Results

Molinia coerulea.—Flying bent or purple melick grass flourishes over a fairly wide range of soil and topographical conditions, but is most often found where there is a high degree of acidity with some impedance of drainage. It is not, however, favoured by wetter conditions with which deer-hair is more usually associated, nor does it occupy the harder moorland soils. Although its season is a short one—it does not start into growth much before the end of April and reaches the flowering stage in late July—it does produce relatively large amounts of green material. Of the value of this material there is little doubt; it provides keep for both cattle and sheep and, according to Wallace [4], both classes of stock do well and fatten on it. It has little value as a winter food, for, as its name implies, a great deal of the dead leaf blows away.

Little information concerning the composition and feeding-value of flying bent is available. The earliest analysis appears to have been that made by Kinch [5] in 1884; since then further work on the composition of the plant has been carried out by Evans [6], Davies and Chippindale [7], Fagan and Davies [8], and Thomas and Dougall [9]. Digestibility data have been obtained by Honcamp and Nolte [10], and Thomas and Ibbotson [11]. These workers showed that the value, or more accurately the potential value, of this grass as a food for livestock has been generally, and perhaps seriously, under-estimated. On analysis it compares favourably in respect of all but one of its major constituents with the best lowland grasses. Little calcium is present at any time, although the content does increase somewhat towards the end of the growing-season. On the other hand, the crude-protein content is high by any standard, and during the first weeks of growth may substantially exceed 20 per cent. of the dry matter. Phosphorus-content is equally outstanding in the early stages and remains at a good level until September. The digestibility of all the organic-matter components, other than ether extract, is also good.

TABLE 1. *Mineral Constituents of Flying Bent* (Molinia coerulea) *at Different Stages of Growth**

Cutting date:	*Feb. 28*	*May 8*	*June 23*	*July 17*	*Aug. 15*	*Sept. 12*
Per cent.:						
Silica-free ash	0·46	5·20	3·53	3·33	2·83	2·45
Silica (SiO_2)	1·95	0·46	0·72	0·70	0·96	1·65
Lime (CaO)	0·142	0·165	0·200	0·215	0·246	0·291
Phosphoric acid (P_2O_5)	0·154	0·927	0·497	0·460	0·346	0·274
Potash (K_2O)	0·15	2·89	2·79	1·56	1·30	1·06
Soda (Na_2O)	..	..	0·063	0·034	0·032	0·042
Magnesia (MgO)	0·085	0·295	0·234	0·229	0·263	0·318
Chlorine (Cl)	0·047	0·452	0·345	0·334	0·350	0·377
Total sulphur (S)	0·089	0·231	0·226	0·227	0·229	0·216
Inorganic sulphur (S)	0·004	0·098	0·097	0·090	0·105	0·083
Organic sulphur (S)	0·085	0·133	0·129	0·137	0·124	0·133
Parts per million:						
Iron (Fe)	139	116	109	94	106	104
Manganese (Mn)	295	283	382	428	330	434
Copper (Cu)	6·59	19·56	6·30	7·98	4·96	5·22
Cobalt (Co)	0·086	0·077	0·106	0·054	0·087	0·041

* The results in this and subsequent Tables are all calculated on a dry-matter basis.

The contents of calcium and phosphorus (Table 1) fully confirm previous findings. Calcium is relatively low at all times but increases appreciably as the season advances. Phosphorus is relatively high in the spring growth, though slightly less than Thomas and Dougall found, a difference probably due to a change of sampling ground. Manganese, iron, copper, and cobalt are not present in larger amount than in good lowland grass, and in this respect flying bent is inferior to common heather, which is an exceptionally valuable source of these elements [1]. Potassium occurs in much greater quantity than in common heather. Very little sodium is present.

These findings suggest that though flying bent is not a particularly valuable source of any of the trace elements, it is a very good complement to common heather in respect of the major minerals concerned; although it is low in calcium, it is by comparison rich in phosphorus.

Scirpus caespitosus.—The deer-hair, deer grass, or spike rush is not generally held to be among the best plants on the hill, although the authorities are not unanimous on this point. Wallace [4] believed it to be nutritious, more especially during the early months of the year, and suggested that it is often an excellent substitute for draw-moss, particularly where there is a good deal of hard land growing white bent. On the other hand, Linton [12] holds that it is not a great favourite with sheep, but admits that it may be grazed or pulled in February or March. Deer-hair flourishes on the poorest types of hill land, under conditions of impeded drainage and often at very high elevation. On the other hand, the plant has only a short season of usefulness; in general, sheep leave off eating it by June or even before, as they can then obtain sufficient food from other sources, and appear to dislike the terminal spikelet.

The composition has been investigated by Kinch [5], Fagan [13], and

more recently by Dougall [14], who concludes that deer-hair has its highest feeding-value during the early spring months when the crude-protein content is satisfactory, and the phosphorus level exceedingly good. The per cent. fibre-content at this time is little higher than in other moorland species at the same stage of growth. Between April and September there is a well-marked and progressive decline in feeding-value. Dougall suggested that deer-hair might have a special function as a phosphorus supplement, and serve to make good the deficiency in phosphorus found in common heather and white bent.

TABLE 2. *Mineral Constituents of Deer-hair* (Scirpus caespitosus) *at Different Stages of Growth*

Cutting date:	*Feb. 28*	*May 8*	*June 23*	*July 17*	*Aug. 15*	*Sept. 12*
Per cent.:						
Silica-free ash	1·34	3·33	3·21	2·97	3·17	2·97
Silica (SiO_2)	0·49	0·40	0·58	0·48	0·54	1·12
Lime (CaO)	0·199	0·201	0·149	0·194	0·273	0·332
Phosphoric acid (P_2O_5)	0·387	0·594	0·360	0·314	0·357	0·226
Potash (K_2O)	0·52	1·83	1·71	1·42	1·59	1·50
Soda (Na_2O)	..	..	0·046	0·051	0·036	0·054
Magnesia (MgO)	0·195	0·294	0·224	0·218	0·232	0·273
Chlorine (Cl)	0·084	0·281	0·312	0·257	0·276	0·321
Total sulphur (S)	0·108	0·154	0·212	0·240	0·249	0·266
Inorganic sulphur (S)	0·021	0·040	0·076	0·088	0·112	0·132
Organic sulphur (S)	0·087	0·114	0·136	0·152	0·137	0·134
Parts per million:						
Iron (Fe)	113	125	99	105	105	110
Manganese (Mn)	247	312	325	353	502	656
Copper (Cu)	5·07	9·90	17·56	7·87	7·57	4·23
Cobalt (Co)	0·087	0·115	0·058	0·084	0·103	0·039

The results (Table 2) relating to phosphorus and calcium confirm the findings of Dougall. It is also clear that deer-hair is a poor source of sodium, even when compared with other moorland plants. Copper is present in rather larger amount than in some of the other non-ericaceous plants examined.

The composition of the ash of deer-hair is very similar to that of flying bent, although the phosphorus-content is slightly less. Nevertheless, this plant must be considered a useful source of phosphorus, but whether it can be anything more than a partial substitute for draw-moss would appear doubtful, assuming the correctness of the conclusion that the particular value of draw-moss lies in its exceptionally high phosphorus-content [2].

Vaccinium myrtillus.—The blaeberry, bilberry, or whortleberry is usually found at high elevation and always on acid soils. Although sometimes found on sands, its more usual habitat is peat, and in northern England it is commonly found on high-lying 'black land' in association with heather. It may be indeed a serious competitor of heather where the latter has been mismanaged. Opinion is much divided concerning the feeding-value of the blaeberry and the extent to which it is consumed

by stock. Stapleton [15] has maintained that it is of little value as pasturage, and of no great use to grouse. In the north, however, there is ample evidence that the blaeberry is a very good food for grouse, and in the authors' view sheep eat it in appreciable amount in certain seasons and in areas where it forms a comparatively large proportion of the herbage.

An investigation into the composition of the blaeberry, by Thomas and Dougall [16], showed that the leaf is rich in crude protein—nearly 19 per cent. of the dry matter—during the early stages of growth, and was reasonably rich in this component throughout the season. Crude fibre was in inverse ratio to protein, being extremely low in spring and at all times present in smaller amounts than in young pasture grass. The major mineral constituents provided results of outstanding interest. The blaeberry, like other members of the Ericeae previously examined by the same workers, proved to be a rich source of calcium; this constituent, present to the extent of approximately 1 per cent. in the spring samples, rose to almost twice that figure in a sample taken at the end of September. The phosphorus-content, though low relative to calcium, was substantially higher than in most other moorland plants. It was therefore concluded that not only was the feeding-value of blaeberry exceptionally high in early summer, but that the plant was also capable of producing nutritious food at all times of the year—even in winter. To what extent blaeberry contributed to the total intake was difficult to assess.

TABLE 3. *Mineral Constituents of the Blaeberry* (Vaccinium myrtillus) *at Different Stages of Growth*

	Leaf				*Green Stem*			
Cutting date:	*June 23*	*July 17*	*Aug. 15*	*Sept. 12*	*June 23*	*July 17*	*Aug. 15*	*Sept. 12*
Per cent.:								
Silica-free ash	3·49	4·21	3·77	3·94	2·72	2·88	2·39	2·43
Silica (SiO_2)	0·23	0·09	0·12	0·11	0·23	0·10	0·01	0·12
Lime (CaO)	0·978	1·235	1·370	1·500	0·926	1·038	0·840	0·974
Phosphoric acid (P_2O_5)	0·541	0·501	0·583	0·468	0·427	0·446	0·498	0·366
Potash (K_2O)	0·95	1·69	0·82	1·02	1·11	0·54	0·41	0·50
Soda (Na_2O)	0·066	0·067	0·085	0·035	0·087	0·075	0·072	0·077
Magnesia (MgO)	0·399	0·525	0·704	0·635	0·348	0·351	0·311	0·292
Chlorine (Cl)	0·375	0·214	0·187	0·133	0·223	0·189	0·051	0·047
Total sulphur (S)	0·287	0·289	0·180	0·181	0·204	0·188	0·122	0·103
Inorganic sulphur (S)	0·086	0·124	0·082	0·045	0·049	0·018	0·008	0·023
Organic sulphur (S)	0·201	0·165	0·098	0·136	0·155	0·170	0·114	0·080
Parts per million:								
Iron (Fe)	143	188	136	193	153	137	124	126
Manganese (Mn)	946	1,335	2,639	2,593	1,648	1,624	1,868	2,028
Copper (Cu)	13·08	13·90	14·40	12·91	14·25	14·60	..	17·74
Cobalt (Co)	0·088	0·088	0·115	0·116	0·068	0·087	0·086	0·106

From Table 3 it is evident that the findings of the earlier work (cf. *supra*) with regard to calcium and phosphorus are confirmed. It is also clear that the green stem is only a little poorer in these constituents than the leaf. Magnesium is present in the leaf in exceptionally large amounts, but there is markedly less in the green stem. As a source of manganese, iron, and copper, blaeberry is one of the best of the moorland plants, being comparable with common heather [1]. Iron and copper

show no particular seasonal trend. Manganese increases with the season, more especially in the leaf. The amount of cobalt present is comparable with that found in the other species examined, but is lower than that found in common heather.

In general, the blaeberry must be considered highly 'mineral-efficient', and it is reasonable to suppose that, on this account alone, it fills a highly significant role in the nutrition of the grouse. As already indicated, the extent to which it is eaten by sheep is somewhat uncertain but, where eaten, it should prove equal to heather in making good the mineral deficiencies which are shown elsewhere in this paper to be characteristic of some of the chief herbage components on 'white' land.

Nardus stricta.—The moor mat-grass, wire bent, white bent, or common nard occurs most frequently on hard dry moors and, according to Wallace [17], more especially among 'lea' or 'yird' heather (i.e. heather which grows on soil without any appreciable covering of peat). It cannot, however, be assigned to one particular habitat, and may occur on soils of very different character. It is believed that white bent has spread to a marked degree during recent times, and now covers large areas of hill land which formerly carried a more productive class of herbage. It appears that the older writers laid considerable stress on its value at certain times of the year and in certain seasons. Contemporary authorities have viewed it with less favour since 'pine' and certain other diseases of hill sheep occur mainly on 'white' land, where white bent is usually the predominant species. It is to be borne in mind, however, that there are immense areas of such land which are not likely to be amenable to radical improvement during the lifetime of anyone now concerned with them. This being so, it would seem that a fuller knowledge of the herbage components, and more especially of white bent, is much to be desired.

Analyses were made by Kinch [5], and more recently Fagan [13] and Dougall [18] who have shown that the earliest growth, sampled in May and June, contains a relatively high proportion of crude protein, together with fair amounts of phosphorus. This level is, however, maintained only for a very short period; at all other times the grass is poor in every respect. The calcium-content is very low throughout the whole year and the silica exceptionally high.

The data obtained by Dougall [18] are fully confirmed in Table 4. The amounts of iron and copper present, as compared with those in common heather or, as will be seen later, with those in other moorland species, are small, especially for copper. During the early stages of growth manganese is at a relatively high level, being present in amounts almost comparable with that found in heather. There is, however, an appreciable fall during late summer and autumn. Total and organic sulphur, chlorine, and the alkali metals all show marked seasonal variation, falling consistently from maxima in spring. In general, the winter sample is extremely poor in all useful mineral constituents.

Whether or not contemporary opinion concerning the worthlessness of white bent is entirely sound, there is no doubt that it preponderates in much of the poorest hill land in this country. As stated above, it is

TABLE 4. *Mineral Constituents of White Bent* (Nardus stricta) *at Different Stages of Growth*

Cutting date:	*Mar. 6*	*Apr. 27*	*June 16*	*July 25*	*Aug. 16*	*Sept. 13*
Per cent.:						
Silica-free ash	0·74	1·76	2·90	2·90	1·50	1·19
Silica (SiO_2)	6·64	4·62	2·68	3·56	6·32	5·79
Lime (CaO)	0·085	0·119	0·116	0·126	0·124	0·105
Phosphoric acid (P_2O_5)	0·259	0·555	0·483	0·404	0·220	0·235
Potash (K_2O)	0·20	1·83	2·20	1·41	1·43	0·65
Soda (Na_2O)	0·054	0·111	0·100	0·048	0·033	0·038
Magnesia (MgO)	0·053	0·154	0·191	0·161	0·176	0·125
Chlorine (Cl)	0·087	0·644	0·422	0·401	0·338	0·241
Total sulphur (S)	0·096	0·238	0·191	0·181	0·175	0·146
Inorganic sulphur (S)	0·028	0·028	0·039	0·061	0·037	0·035
Organic sulphur (S)	0·068	0·210	0·152	0·120	0·138	0·111
Parts per million:						
Iron (Fe)	111	141	75	85	86	89
Manganese (Mn)	137	718	469	548	588	350
Copper (Cu)	3·55	7·74	4·48	5·62	4·06	3·80
Cobalt (Co)	0·097	0·080	0·092	0·078	0·112	0·117

equally certain that some of the most troublesome diseases of hill sheep have their highest incidence on such land. It would be rash to assume that the poverty of the benty hill, or the increased incidence of disease which may be associated with it, are due entirely to mineral deficiency, although that assumption is sometimes made. The results shown above do suggest that the ash of white bent has certain remarkable features. The silica-content, which is much higher than that of any other common moorland plant, may have a possible significance—apart from the association of a high silica-content with a reduced palatability. No other species is poorer in calcium or copper, but the cobalt-content is no worse than in other components of the typical 'white land' sward, and does not fall below the deficiency level for sheep accepted by many workers. On the whole, the results here obtained do suggest that mineral deficiency may be a major factor in the causation of those diseases often associated with the grazing of hill land that is largely covered by white bent. Moreover, the evidence points to calcium and copper as being those elements of which there is a most serious deficiency. Cobalt should not be ruled out entirely, as the samples of white bent used in this investigation were not from 'pining' land.

Juncus squarrosus.—The widely held belief that members of the rush family are of negligible feeding-value is a mistaken one, and this applies more especially to the heath rush or stool bent. Stapledon and Hanley [19] have said that 'on the Fescue-agrostis and Nardus pastures alike, the heath rush (*Juncus squarrosus*) is probably the most valuable grazing plant contributing to the herbage'. It is probable that this plant is of no less value on heather moor which has been recently burned. Of the limited number of species which provide keep during the two or three years that must elapse before the heather again comes into full productivity, stool bent is often the most important. The fact that the plant

is evergreen adds to its usefulness, although its habit of growth precludes its being very easily reached in deep snow. The flowers and seed heads are readily eaten by the moorland game birds.

The composition of stool bent has been investigated by Thomas [20], who concluded that it is not outstanding in respect of any one food constituent. He adds that 'as a quantitative supplement at opportune times, and under certain clearly defined circumstances, e.g. on "white land" pasture in winter and on heather moor after burning, stool bent is of considerable value to the hill farmer'.

TABLE 5. *Mineral Constituents of Stool Bent* (Juncus squarrosus) *at Different Stages of Growth*

Cutting date:	*Mar. 6*	*Apr. 27*	*June 16*	*July 25*	*Aug. 16*	*Sept. 13*
Per cent.:						
Silica-free ash	2·94	4·03	4·26	3·68	3·12	2·79
Silica (SiO_2)	0·52	0·21	0·26	0·33	0·15	0·16
Lime (CaO)	0·097	0·098	0·112	0·112	0·108	0·096
Phosphoric acid (P_2O_5)	0·459	0·417	0·485	0·420	0·287	0·289
Potash (K_2O)	1·48	2·18	2·49	1·83	1·72	1·38
Soda (Na_2O)	..	..	0·211	0·208	0·190	0·168
Magnesia (MgO)	0·213	0·237	0·283	0·266	0·274	0·254
Chlorine (Cl)	0·668	0·867	0·665	0·583	0·604	0·563
Total sulphur (S)	0·147	0·242	0·220	0·200	0·160	0·134
Inorganic sulphur (S)	0·088	0·158	0·098	0·060	0·050	0·037
Organic sulphur (S)	0·059	0·084	0·122	0·140	0·110	0·097
Parts per million:						
Iron (Fe)	140	146	129	107	116	155
Manganese (Mn)	106	165	270	280	168	162
Copper (Cu)	5·19	8·62	8·09	6·49	12·76	7·15
Cobalt (Co)	0·081	0·072	0·089	0·078	0·106	0·048

The results in Table 5 show that stool bent is a very poor source of calcium. The percentage present remains constant throughout the season, a finding which conflicts with the earlier work. Useful, though not outstandingly large amounts of phosphorus are present during spring and summer, but there is a fairly consistent fall throughout the growing-season. Both sodium and chlorine occur in larger proportion than in any of the other moorland plants so far examined; both decline somewhat with advancing season. Iron and copper are present in relatively large amount; cobalt figures are about average for moorland species and manganese is low.

Any outstanding value which stool bent may possess is probably due to its evergreen nature and to the rapid regrowth on newly burnt black land, thus providing a stop-gap. It should be noted, however, that it is rich in sodium and chlorine, being comparable with good pasture grass in this respect, and much superior to any of the other common moorland plants. As a source of copper it is useful, although by no means so good as ericaceous species like common heather and blaeberry, but it is decidedly poor in manganese.

Eriophorum vaginatum.—The draw-moss or sheathing cotton-grass

has probably received more attention from writers on hill farming than any other moorland plant, and there are innumerable references in the literature to its value as a sheep-feed. This plant is usually found on peat at high altitudes and invariably grows best under wet conditions. This characteristic is one which should always be borne in mind when the draining of hill land is undertaken. It is during early spring that draw-moss is of maximum value to hill sheep, and in a good year it may provide grazing in January. The blanched leaf-butts—the 'scallions' of the hill shepherd—are held to be particularly nutritious.

The early work of Kinch [5] did not provide evidence that the known usefulness of draw-moss was due to its possession of any exceptional qualities as a feeding-stuff, and it appears to have been assumed that the value of the plant was due to its availability at a period of the year when other fodder was scarce. It should be noted, however, that this worker did not examine the composition of the ash. A more recent investigation by Thomas [2] showed that whilst the plant as a whole contained much phosphorus, the 'scallion' was particularly rich in it. He suggested that draw-moss formed a perfect complement to common heather, which is relatively poor in phosphoric acid, and that this must be considered an important factor in the usefulness of the plant as a spring-feed for hill sheep. He showed, further, that draw-moss was an extremely poor source of calcium (Table 6).

The percentage of phosphoric acid found in the 'scallion' is even higher than that reported by Thomas [2], although the first sample was not taken until August 16. As the April sample of the plant as a whole contained nearly 0.9 per cent. of phosphoric acid in dry matter, it is obvious that the leaf-butts must have been exceptionally rich in this nutrient during spring. The amount of calcium in both leaf and butt is poor, but slightly higher than that found in the previous work referred to above. The potassium-content of the 'scallion' is almost as high as in good pasture grass, but the remainder of the plant does not constitute a particularly valuable source. Iron, copper, and cobalt are all present in the leaf-butt in quantities comparable with those found in heather. Moreover, the possibility of soil contamination is, in this case, considered to be negligible.

The value of draw-moss as a sheep-feed cannot be disputed, and in view of the results here presented it is very difficult to avoid the conclusion that this value is due to the high mineral efficiency of the plant, and more especially of the butt. The relatively large amounts of copper and cobalt present may be significant, but probably the high phosphorus-content is the most important factor, for there is no other moorland plant which is known to the authors with such a consistent high level of phosphorus.

Summary and Conclusions

Of the six species examined in this investigation, blaeberry (*Vaccinium myrtillus*) is the only one which, like heather, contains substantial proportions of calcium. The remaining five prove to be very poor sources of this element, and show an ill balance with phosphorus. The extent to which blaeberry is consumed by sheep is somewhat uncertain,

TABLE 6.—*Mineral Constituents of Draw-moss* (Eriophorum vaginatum) *at Different Stages of Growth*

	Leaf and butt						*Leaf-butt*		*Leaf*	
Cutting date:	*Mar. 6*	*Apr. 27*	*June 16*	*July 25*	*Aug. 16*	*Sept. 13*	*Aug. 16*	*Sept. 13*	*Aug. 16*	*Sept. 13*
Per cent.:										
Silica-free ash	1·10	2·72	3·09	2·75	2·53	2·62	4·35	4·32	2·54	2·81
Silica (SiO_2)	0·82	0·12	0·60	0·39	0·44	0·40	0·55	0·48	0·49	0·92
Lime (CaO)	0·204	0·204	0·255	0·217	0·240	0·195	0·249	0·219	0·204	0·106
Phosphoric acid (P_2O_5)	0·330	0·864	0·601	0·605	0·513	0·365	1·018	0·690	0·491	0·445
Potash (K_2O)	0·35	1·19	1·29	1·18	1·06	1·39	2·56	2·18	1·00	1·33
Soda (Na_2O)	0·072	..	0·054	0·048	0·050	0·075	0·086	0·053	0·065	0·049
Magnesia (MgO)	0·214	0·366	0·301	0·311	0·273	0·287	0·386	0·376	0·287	0·296
Chlorine (Cl)	0·108	0·113	0·073	0·051	0·053	0·107	0·297	0·411	0·075	0·046
Total sulphur (S)	0·094	0·167	0·240	0·169	0·180	0·172	0·207	0·208	0·201	0·181
Inorganic sulphur (S)	0·040	0·073	0·096	0·043	0·040	0·052	0·125	0·063	0·039	0·056
Organic sulphur (S)	0·054	0·094	0·144	0·126	0·140	0·120	0·082	0·145	0·162	0·125
Parts per million:										
Iron (Fe)	108	103	205	96	176	143	164	280	124	123
Manganese (Mn)	224	296	177	180	149	139	212	283	141	151
Copper (Cu)	5·94	9·61	8·65	7·52	12·07	8·24	12·67	11·30	7·62	7·78
Cobalt (Co)	0·080	0·079	0·058	0·063	0·033	0·082	0·260	0·143	0·067	0·082

although this plant undoubtedly constitutes a substantial fraction of the diet of the grouse. The value of a mixed moor on which sheep have access to, at least, some heather is therefore evident.

Two species contain amounts of phosphorus comparable with those found in the best cultivated grasses. Draw-moss (*Eriophorum vaginatum*), and more especially the 'scallion' or leaf-butt, is an exceptionally good source; the results obtained in this work fully confirm those found on a previous occasion. For a brief period, during the earliest stages of growth, the flying bent (*Molinia coerulea*) is almost equally good in this respect.

The stool bent (*Juncus squarrosus*) has a high content of sodium and chlorine, and white bent (*Nardus stricta*) in early spring contains an appreciable amount of chlorine. Flying bent and the 'scallion' of draw-moss are probably among the best sources of potassium. It is noteworthy that blaeberry is not a good source of chlorine or of the alkali metals. Common heather (*Calluna vulgaris*) [1] and bell heather (*Erica tetralix*) [2] have been shown to have the same characteristics. It is, therefore, possible that the ericaceous plants as a whole are deficient in these elements.

There is great variation between species in contents of iron, manganese, copper, and cobalt. The blaeberry and the 'scallion' of draw-moss are very good sources of iron and copper, but white bent is distinctly poor in both. Blaeberry is also outstanding in its manganese-content, but draw-moss is not a good source, even the 'scallion' being relatively poor in this respect. Eriophorum does, however, contain markedly larger amounts of cobalt than any of the other species examined. Blaeberry is not as rich in this element nor white bent so poor as had been expected; the last finding is of interest in view of the dominance of white bent on swards associated with 'pine'.

Draw-moss appears, on the whole, to be a better source of minerals than any other plant on the hill. This conclusion refers to the leaf-butt or 'scallion', but it should be remembered that at the period when this plant is most avidly eaten, i.e. in the early spring months, the 'scallion' will constitute by far the greatest proportion of the material consumed. Admittedly, draw-moss is poor in calcium and manganese, but, as already mentioned, common heather is an excellent supplement, being an extremely good source of both these elements. On the other hand, white bent is almost certainly the least 'mineral-efficient' of the moorland plants. The silica-free ash is extremely low, and there is no single element of which it can be considered a really good source. It should be added that the silica-content is very high at all stages of growth, and on occasion may exceed 6 per cent.

It is well known that graziers believe that a 'mixed' moor provides the best type of hill grazing, and it is suggested that the results which have been presented here provide a substantial basis for this belief. Where there is a balanced mixture of species, with reasonable proportions of heather and odd patches of draw-moss, diseases due to mineral deficiency are unlikely to occur. Areas containing little or no heather, blaeberry, and draw-moss are likely to be deficient in one or more elements, what-

ever other moorland species may be present; but it is, above all, on 'straight' white-bent moor that deficiencies will be most prevalent.

If it be assumed that the re-seeding of hill land is never likely to be practised on any considerable scale—and the assumption is probably justified—then the obvious means of ensuring a mineral-efficient sward would seem to consist in encouraging such indigenous species as have been shown to be richest in those mineral elements known or believed to be essential to the proper nourishment of grazing stock. Incidentally, any increase in such species would almost certainly result in an all-round improvement in the nutritive value of the sward as a whole. The subject of hill-land improvement is outside the scope of the present paper, but investigation on the lines suggested might be profitable. The effects of manuring and of draining on the balance of indigenous species should be studied, bearing in mind that not all of the most useful moorland plants flourish on dry moor.

Acknowledgement.—The authors desire to acknowledge the assistance they have received from Miss D. Lamb.

REFERENCES

1. B. Thomas, J. R. Escritt, and N. Trinder, Empire J. Expt. Agric., 1945, **13**, 93–9.
2. B. Thomas, J. Min. Agric., 1935, **42**, 458–61.
3. H. W. Dougall, Thesis for the Degree of Master of Science, King's College, University of Durham, 1939, Appendix.
4. R. Wallace, Trans. Highland and Agric. Soc. Scotland, 1884, **16**, 250.
5. E. Kinch, ibid., 1884, **16**, 273.
6. R. E. Evans, Welsh J. Agric., 1927, **3**, 119–47.
7. R. O. Davies and H. G. Chippindale, Empire J. Expt. Agric., 1934, **2**, 324–36.
8. T. W. Fagan and R. O. Davies, Rept. 4th Intern. Grassland Conf., Aberystwyth, 1937.
9. B. Thomas and H. W. Dougall, J. Min. Agric., 1939, **46**, 277–81.
10. F. Honcamp and O. Nolte, Landwirtschaftl. Versuchs-stationen, 1919, **93**, 91.
11. Unpublished data.
12. A. Linton, The Grazing of Hill Pastures, 1918.
13. T. W. Fagan, Welsh J. Agric., 1932, **8**, 145.
14. H. W. Dougall, loc. cit., pp. 43–51.
15. R. G. Stapledon, The Hill Lands of Britain, 1937, p. 53.
16. B. Thomas and H. W. Dougall, J. Min. Agric., 1938, **45**, 546–52.
17. R. Wallace, Heather and Moor Burning for Grouse and Sheep, 1917, p. 39.
18. H. W. Dougall, loc. cit., pp. 7–20.
19. R. G. Stapledon and J. A. Hanley, Grassland: its Management and Improvement, 1927, p. 18.
20. B. Thomas, J. Min. Agric., 1936, **43**, 262–5.
21. Unpublished data.

(*Received May 18, 1947*)

PULSE GRAIN CROPS IN THE MIDDLE EAST

HAROLD H. MANN

PULSE grains are specially important in countries that are mainly vegetarian, such as the greater part of the Middle East and of Africa, where the pulse grains form almost the only source of the high-grade protein necessary for man and beast. The proportion of the cultivation taken up by pulse crops varies with the extent to which the people depend on vegetable sources for their food. Where milk is scarce owing to the limited amount of milking stock, we find the highest proportion of leguminous grain crops: where grazing is more plentiful and milk more abundant, the proportion of leguminous grain crops goes down. To take an extreme case, in parts of India, like Bombay, the pulse grain crops amount to over 17 per cent. of the cereal area, but in Turkey, where more milk is available, thanks to 'oasis cultivation', they occupy from 5½ to 8 per cent. of the cereal area, and this proportion seems to apply to much of the Middle East. In Africa, under somewhat similar conditions, Hall [1] suggested that the peasant cultivator should aim at having half of his arable area under cereals, a quarter under beans and peas, and a quarter under roots and green vegetables.

Although the need of such leguminous grain crops is fully recognized in the Middle East, and although they are found everywhere, they are often cultivated as catch crops between the more valuable cereals. The actual crop used is that which can be squeezed into the time available between the dates fixed either by other crops or by the weather. In Palestine, for instance, they are among the crops termed *kerabs*, and may be grown either in the cold weather (beans, lentils, vetches), or in the spring (late lentils, chickpeas, cowpeas) when the harvest may extend into the hot season [2]. The essential part they play in the agricultural economy seems to have been recognized from very early times, and the improvement of many leguminous plants to make them economical producers of grain is at least as old as the similar improvement of cereal crops. The Middle East, and Turkey in particular, seems to have been the place of origin of many of our pulse crops. Vavilov [3], who has studied this subject more carefully than any other worker up to date, thinks that we owe to SW. Asia and the parts of Europe round the eastern Mediterranean the discovery and development of peas, both large- and small-grained, broad beans, lentils, vetches, chickpeas, and possibly several others that are now grown throughout the world. So improved are the types grown, as compared with their wild congeners, that some authorities, like Popov [4], have suggested that 'an ancient agricultural people having lived in Asia Minor, deliberately, *according to principles and methods now lost*, artificially created a whole set of cultivated plants', among them being several types of pulse grown for grain.

The variety of leguminous grain crops in western Asia and the adjoining parts of Africa is far less than it is in India. Many that are produced

on a large scale in India, such as pigeon peas (*Cajanus indicus*), are almost if not quite unknown in our area. The Turkish statistics quote the area under eight different leguminous grain crops: to do the same in India, for crops relatively as important, it would be necessary to quote twenty. This review deals with the eight crops referred to there, with a few remarks about two or three others that have a smaller but still important place in the economy of the region.

Chickpeas

The chickpea (*Cicer arietinum*) has been known all over western Asia since prehistoric times, and was mentioned by Homer (*Iliad*, Bk. xiii). Most probably it originated in the tract of country between the Caucasus and the Himalaya, but no wild form is known at present. Its cultivation now extends from Morocco to Tibet, but is much more important in the eastern part of this area than in the west. From Asia Minor to Persia its cultivation is practically continuous, and the greatest diversity of type occurs in Persia.

Chickpeas form, in fact, one of the most important food crops over all the Middle East. They have several advantages over most other leguminous grain crops. They can be grown both in the winter and the summer, though they are not naturally a tropical crop. They can be produced with or without irrigation, and there are varieties like *Cicer pinnatifida*, with very small seeds, which grow in semi-desert conditions. The ordinary yield in the most suitable localities is about 700 lb. grain per acre on unirrigated land, and 900 lb. per acre under irrigation. When seed from Anatolia was taken to Russia for cultivation, yields of 600 to 900 lb. per acre were obtained [5].

Over most of our area the character of the plants grown is very similar; they are well branched and erect, and about 12 to 14 in. in height. Types with small leaves occur in Abyssinia, but apparently not elsewhere. Flowers are large except in a few varieties in Abyssinia and Persia. The number of pods per plant varies from 45 to 160.

The chickpea grows on all kinds of soil unless these are too sandy or too wet, but to get the best results the land should be deep and fertile; it does not need a fine tilth, and a deep seed-bed is more important than a finely pulverized one. The leaves of the growing plants secrete an acid liquid at night-time which contains much malic acid [6] and is used as medicine over much of southern Asia. The various varieties ripen after very different periods but the average is perhaps about 90 days. The two objections to chickpeas as a crop are: (*a*) its susceptibility to cold, especially to sudden bursts of cold, and (*b*) the uselessness of the remainder of the plant as cattle feed. On the other hand, in India it is a favourite crop of the cultivators who regard it as a restorative of the soil.

Although this plant can be grown as either a summer or winter crop, its sensitivity to cold precludes its cultivation where frosts may occur. In Egypt it is always grown as a *shitwi* or winter crop, being sown in Lower Egypt in early November and in Upper Egypt a little earlier. The yield expected is about 1,200 lb. per acre, under irrigation. In

Palestine it is one of the favourite crops of the *fellahs* in the north, and is always grown as a spring *kerab*, being sown between the first and the later rains, ripening in June or July. It is almost the only leguminous grain crop that will grow at this time of the year. It is cultivated almost all over Turkey except in the very wet parts of the Black Sea coast and in the high plateau of Kars. In 1942 there were about 240,000 acres under chickpeas (about 22 per cent. of the area under grain legumes), and the yield was estimated at 53,000 m. tons of grain. The status of chickpeas in Iraq and Persia is lower, but they are grown there with success in winter under irrigation either alone or mixed with barley, at least when the winter is not too cold. Chickpeas are found in Afghanistan, especially in the Herat plain, and there is a great diversity of forms in that country [7]. In Cyprus they are grown to a limited extent, and are always used locally, chiefly for the confectionery trade [8].

I suppose there is hardly a leguminous grain in our area which is more important for human food than chickpeas, though, curiously enough, they were considered as impure in ancient Egypt (Herodotus). The grain is consumed, there and elsewhere, as a suitable food for the working classes. Like other leguminous grains, it is usually parched and then eaten with or without oil, either whole or made into coarse meal; or it is ground into flour, mixed with other kinds of grain, and then made into cakes; or it may be steeped in cold water till it swells and then eaten alone or with salt. The average percentage composition of the unhusked grain is: protein 18–20, fat 4½, ash 3. Husking decreases the content of fat.

Vetches

The various forms of vetch probably originated in the Middle East and specifically in Asia Minor, from where the crop spread at a comparatively late date to most of Europe. In Anatolia there are now very many species either growing wild as weeds in corn and other crops, or as admixtures in the generally cultivated species. The vetches grown as crops belong to three types: (*a*) *Vicia sativa*, the common vetch, (*b*) *Vicia ervilia*, the ervil or black bitter vetch, and (*c*) *Vicia tenuifolia*, a semi-cultivated species more hardy than the common vetch. Taken together, they occupy an area, in some countries at least, greater than that of any other similar group of crops. In Turkey, for instance, in 1942 there were 340,000 acres under vetches or nearly 32 per cent. of the area under grain legumes. They form a very important animal food, as well as a rather inferior pulse for human consumption. As usually grown, the crop is very polymorphous, and, according to Zukhovsky [5], the Anatolian vetches are exceptionally variable, possessing a large number of recessive characters. Forms bearing subterranean flowers and giving seeds and pods are not at all rare. There is every evidence that in the Middle East we have some of the most precious material for improving groups of crops which may become very important in that region.

(*a*) *Vicia sativa* occurs as a crop in two easily recognizable sub-species, *turcica* and *angustifolia*. The latter has very little importance, and may

be branded a noxious and poisonous weed (*v.i.*). The former occurs in many forms, whose distinctive characters are: large size of the seeds compared with those found farther east; resistance to drought, which is far greater than that of the common European species; a much more erect and stalwart habit than is usually found in the West; the less marked dehiscence of the pods (though vetches always are more dehiscent than other legumes); and the quite high yields that are attainable.

Vetches are very scarce indeed in the irrigated areas of Egypt and Iraq, in the wet regions of the Black Sea coast in Turkey, and in the higher lands of Armenia and adjoining areas. They are grown in Persia, even in the tribal areas, but they are most at home in Anatolia, Syria, and Palestine. In Turkey they are mainly cultivated on the plateau of Asia Minor, in areas where the rainfall is 300–500 mm. and the distribution typically Mediterranean. They are usually rotated with wheat or other cereal, or with fallow, and are essentially a winter crop. In Syria and Lebanon the usual rotation is wheat, fallow, and then lentils or vetch, the crop being specially grown in the Bekaa valley, the Hauran, and in Aleppo [9]. The crop usually needs 80–90 days to ripen, counting from the date of germination. It is curious to see how vetches disappear from the cultivated plants as one proceeds from west to east in our area, i.e. on going from the Mediterranean to the monsoon type of climate on approaching India.

The seed of *Vicia sativa* is grown chiefly for animal consumption, and is looked upon as a very inferior human food, used only by the poorer classes. It is, nevertheless, a highly nitrogenous food, giving (as grown in Anatolia) about 25 per cent. of protein, or rather more than the common European vetch. The vetch seed grown in the East has been suspected of causing paralysis in cattle if constantly fed; this has been proved to be due to the sub-species *angustifolia* which occurs as a weed among vetch crops, as well as among those of *Lathyrus sativus*. It has been shown [10] to contain a toxic alkaloid (vicin), especially when immature; the seeds scatter almost explosively, and land once infected with it is almost impossible to clean. At present this weed does not seem to be widely distributed in the Middle East, but the danger makes it imperative to replace the very mixed crops of vetch that are now grown with purer and better types.

(*b*) *Vicia ervilia* is grown on a very large scale in the Mediterranean region but only to a very limited extent elsewhere in the world. Unlike the common vetch it is an upright plant, 2–3 ft. tall, without tendrils. It has been cultivated in this region from prehistoric times, and in Anatolia, Syria, and Palestine it is almost an essential part of the agriculture, being grown almost entirely as a grain for feeding animals. In Anatolia it is most abundant on the central plateau, and nearly 20 per cent. of the whole produce of Turkey is grown in the Tokat and Sivas districts: east of this it largely disappears as a crop. In Syria and Palestine, under the name *kersenneh*, it is very commonly grown by peasants as a winter or spring *kerab*, being sown from November to February [9]. It is the vetch most largely grown in Cyprus, where it is the chief legume for animal consumption [8].

The possibilities of the crop have been much studied by Russian workers, who have found that with this, as with other leguminous seeds, there is a tendency for the grain to become smaller as one proceeds east from the Aegean sea. Analysis of the grain derived from Anatolian samples showed a very high content of nitrogen (4·36 per cent.), equivalent to over 27 per cent. protein [5].

Experiments in northern regions have shown this crop to be very resistant to cold, and even in Alaska it has withstood the winter and come up well in the spring. Yields are good though variable: experiments in America have given up to 37 bu. of seed per acre on heavy land, though much less on a light loam. The seed habits are good, as the pods shatter much less than those of most other vetches. It has been stated that the seed can be grown so cheaply that it has been imported into England for stock-feed.

One cannot help thinking that there is an opening for a largely extended cultivation of this pulse for stock-feeding, and that an export trade might be developed if it were carefully studied and the best varieties determined. At present, even where it is grown, it is a rather despised crop, used in Palestine as a half-summer *kerab*, so that the land can remain bare in winter and yet give a good crop later. For this purpose the only plants that can compete with it are late varieties of lentils and chickpeas [2].

(*c*) *Vicia tenuifolia* is reported as semi-cultivated in Cyprus [8]. It grows on the banks and terraces of vineyards between 2,000 and 4,000 ft. elevation, and is harvested and used in exactly the same way as *V. ervilia* in the lower regions. The root-stock is perennial. Littlejohn [8] informs me that he doubts whether it has even been sown, though in some areas it is quite a valuable minor crop.

Lentils

The lentil may almost be called the typical legume of the Mediterranean area, and hence of western Asia. It is very widely grown in Turkey, Syria, and Palestine, and to a considerable extent in almost all the countries of the Middle East. Though it is widely cultivated in India it is not a native of that country, but appears to have originated in the mountains of eastern Anatolia, or Persia, or possibly in the Hindu Kush. As with other legumes in these regions, the farther west one goes, the larger is the size of the grain, but the smaller-grained types predominate in the Middle East. Lentils are popular because their culture is easy and they are attacked by very few pests and diseases. The yield is relatively high, and the small-grained types, especially, ripen rapidly and so suit the conditions where the crop is grown.

Lentils occupy about 10 per cent. of the area under pulse grain crops in Turkey, the largest area being in the district of Urfa, where the rainfall is 412 mm., and almost entirely concentrated in the 6 months ending in April. In Palestine the annual production per annum may rise to 5,000 tons, and the yield varies from 600 to 800 lb. per acre without irrigation. The crop grows on almost all kinds of soil: low-lying soils if light are very suitable. It can be sown from the beginning

of the rains until February [9], and if sown late it allows the ground to be cleaned before the seed is put in. In a typical peasant's holding in northern Palestine or Syria there may be, in any year, about one-twelfth of the wheat area under lentils, a similar area under *kersenneh* (*Vicia ervilia*), and double this amount under chickpeas.

In Egypt lentils are grown chiefly under basin irrigation, but to a small extent on canal banks. In the former case the seed is broadcast in mud and no further watering is given. On canals two or three waterings are required. The crop is often mixed with beans, barley, or wheat. It is harvested by pulling up, and if a mixed crop has been grown, all the produce is threshed together and the seeds separated afterwards. The yield of a good lentil crop is about 1,500 lb. per acre, and the stalks form an excellent food for stock; in Egypt they are thought to be especially good for milking animals.

Farther east, in Persia, lentils form one of the principal pulse crops and some are exported. They can be mixed or rotated with wheat or barley where the winters are not too cold on the Persian plateau. In Afghanistan lentils are grown up to an elevation of 9,000 ft. and occupy the second place among the pulse grains. The types grown there are small-seeded, the large-seeded varieties being quite unknown.

Among the legume grains grown in the Middle East, the lentil seems to possess the best chance of developing into a material of international trade. At present imports into the United Kingdom come chiefly from south Europe and the Mediterranean, with a smaller amount from India. It would appear that the market could absorb a much larger supply than is available now, for the grain is an excellent food, forming, as it does, the essential ingredient of a number of invalid diets, and could be worked up into compound feeding-stuffs if the price were reasonable. The crop is easy to grow, yields well, and there are enough wild or semi-wild types already growing in the Middle East to form a basis for improving the varieties that are now grown [12].

Beans

The broad bean (*Vicia faba*) and the haricot bean (*Phaseolus vulgaris*) are both very widely cultivated throughout the Middle East. Though both are often treated as a vegetable and consumed in the green condition, together they form one of the mainstays of leguminous agriculture in almost all the countries with which we are dealing. One or two other types of *Phaseolus* (*mungo*, *radiatus*, *aconitifolius*) are grown near the Indian border, but over the greater part of our area the two named above are those most widely cultivated.

In Egypt the chief bean grown is *Vicia faba*, and there are two types in large-scale cultivation, the small field variety known as *beladi* and a larger type known as *roumi*, the latter being evidently an importation. Both are used as human food, the *roumi* entirely so, whilst the other is also fed to stock. Beans of one sort or another have been known in Egypt from the time of the earliest dynasties.

The soil and climate of Upper Egypt are more suitable for broad beans than is the lower valley of the Nile. With basin irrigation the

seed is broadcast as the Nile falls and is then trodden in; by canals the seed is dropped after the second ploughing, or broadcast and ploughed in. Beans are usually sown in September or October. They must be sown early enough for the crop to be cut before the *khamseen* wind arrives in spring. They take 4½–5 months to ripen, and in Upper Egypt they should be reaped by March. As is well known, the crop must be reaped before it is fully ripe or the seed shatters. The straw is useless for feeding, but it may be used as fuel in brick-making [13]. A recent estimate of the annual production gives about 175,000 acres in both Upper and Middle Egypt, and 130,000 acres in Lower Egypt, or a total produce of over 300,000 tons of beans [14].

The haricot bean is also grown in Egypt but is less important than the broad bean. It also is said to date from very early times, though it is more than doubtful whether it is an old-world plant at all. Even now it is grown mostly in gardens and as a vegetable rather than as a pulse. Attempts have been made to acclimatize American varieties in Egypt, but none of the types imported did any better than the rust-resistant types which already exist there [15].

In Palestine and Syria the haricot bean is a very new culture and not yet extensively grown. The seed is usually sown in January–February, and so far it has been chiefly used as a vegetable crop, being taken green [9]. On the other hand, broad beans are largely grown on the coastal plains of Palestine and on the plateaux to the north, but are rarely seen in the south. They have been found to respond to phosphatic manuring at Rehovoth, and were there sown early in November and reaped at the beginning of March. Heavily manured, broad beans gave a very large yield under irrigation, three times that obtained without irrigation. The worst feature of broad beans as a Palestine crop is their great susceptibility to drought, and hence they are not very reliable for unirrigated cultivation [16].

In Turkey both kinds of bean are grown on a very large scale. The broad bean is grown almost exclusively in the west of Asia Minor, near the Aegean Sea, where the rainfall is typically Mediterranean and the winter temperature not low enough to endanger the crop by sowing in autumn. The total annual rainfall in this region is about 600 mm. A similar climate accounts for an extension of the broad-bean crop to the south-coast areas of Turkey (Adana and Antalya). On the other hand, the haricot bean has its centre very much farther east, and its cultivation is perhaps most intense on the Black Sea coast, particularly in the Samsun district. It is, however, found all over the central plateau except in the highlands of the east. The best types of haricot bean are grown in NE. Anatolia. Varieties with white grains predominate, but the beans are very much mixed, brown and white. The two bean crops occupy about 35 per cent. of the leguminous grain area in Turkey.

On proceeding eastward from Turkey, all the countries in our area grow both the types of beans we are discussing, but the importance of *Phaseolus vulgaris* tends to become smaller and smaller. The usual type of bean on the Persian plateau is *Vicia faba*, and that is grown all over the country, but especially in Isfahan, Azerbaijan, Kerman, Kermanshah,

and Teheran. The whole production of the country is about 170,000 tons, and there is a small export. In Afghanistan, the broad bean is a common food of the mountain population. The Afghan beans are small, especially in the east, for even in Afghanistan the size increases as one goes west. The broad bean probably originated in this region, where it is grown to an elevation of 10,000 ft.

Returning to the Mediterranean, both the beans under discussion are grown in Cyprus. The broad bean is the chief legume grown for human consumption, and only a large-seeded variety is cultivated. The production is about 3,000 tons per annum. The haricot is much less important, though it is grown fairly widely under irrigation, both bush and climbing varieties being produced.

Peas

The ordinary pea, though of little importance as a pulse grain crop, is of great interest from a climatic point of view: its cultivation is limited to temperate conditions, and to the colder parts of the year, disappearing where hot weather may occur during its period of growth. As a result, it is of little importance in Turkey, being grown only on about 5,000 acres, mostly in gardens for the production of green peas. In Palestine peas succeed well on heavy or sandy clay soil, but they failed on land that was at all marshy. They were planted in October or November at Rehovoth: later than this they were not a success [16]. They took about 100 days from seeding to harvest. In Egypt there has never been a large-scale cultivation, but they are grown in gardens for the production of green peas, being sown in October and reaped 3 months later.

To the east of our region, and on the higher levels, peas become much more important, and in the north of Persia and in Afghanistan they are one of the dominant leguminous crops. They are very common in the Pamir region and to the south-west of it, which Govorov [18] regards as the probable original home of the progenitor of the cultivated pea. The cultivation does not extend into central Asia, the Pamir mountains acting apparently as an impassable barrier [7]. In Afghanistan the area under peas is greater than that of any other leguminous grain, and they are cultivated up to 10,500 ft. Most common are the small greenish types with a double pattern on the skin of the seed, such as brown marbled with purple dots, which characterizes the peas of Afghanistan and NW. India.

Cowpeas

The cowpea (*Vigna sinensis*) is another pulse grain which has become very important in the last few years. It undoubtedly originated in central Africa, but has now spread over the greater part of the semi-tropical regions of the world. It is not yet grown on a very large scale in any of the countries of the Middle East, but probably has more of a future than any of the other pulses. It is, however, definitely a sub-tropical plant and cannot be grown where frosts may occur; but will stand a great deal of heat, and so may be kept on the land later in the hot season than other pulses, with the exception of chickpeas.

Hence, in Palestine, under irrigation, its time of harvest is said to be September [9].

There are, however, a good many obstacles to extending the cultivation of the cowpea. In Palestine, at least in the south, its growth without irrigation was unsatisfactory. In choosing a variety to be grown under irrigation, the points of especial importance are high yield, uniform ripening, pods that do not crack, resistance to disease, and a length of life compatible with the water-supply. Early sowing leads to a bigger crop, but this needs more irrigation-water. In practice, in south Palestine it has usually been sown at the end of April or in May, but it may be put in up to August. The yield can be very high, but the crop needs irrigation every 8 or 10 days [6]. In Palestine the crop is gaining ground every year, and it does best in the coastal region; it is, however, very susceptible to weeds.

Cowpeas have also been grown successfully in Egypt for many years; the best variety, 'Asmerli', is said to have been introduced from the Near East. The crop is mostly used by the middle classes, and there seems no reason why it should not be much more extensively grown than it has been up to now.

In Turkey cowpeas are much cultivated in western Anatolia, but the total area has not exceeded 15,000 acres. It is obviously a new crop there, but it seems to be spreading. Most of the varieties grown have a growing-period of from 50 to 100 days, the longer time being taken in a humid climate. In such a humid climate, however, it does not remain healthy in the summer: it would seem to need plenty of water for growth but a dry atmosphere for ripening.

Other Pulse Grains

There are two or three other leguminous grain crops that may be discussed very briefly. Perhaps the most important of these is *Lathyrus sativus*, which is grown extensively in certain parts of our area. Its peculiar virtue is that it can be grown under drier conditions than most other pulses, and so is almost limited to areas where better crops cannot be successful. Its stems form a very good fodder. The bad reputation of the grain as a food for humans and cattle has already been mentioned. In India it seems to have been clearly proved that Lathyrus is not the cause of the paralysis, but rather a variety of *Vicia* (*V. sativa* var. *angustifolia*) which very frequently is found as a weed in the crop [10]. Hence its reputation for being injurious varies from district to district according to the amount of this weed admixture.

Lathyrus sativus is a cold-season pulse commonly sown on heavier soils, particularly on rice fallow and on land that may have been submerged during the rainy season. In India the seed is often sown broadcast and left to take its chance. By the time the plants are in flower the crop completely covers the ground and consists of an intertwined dense carpet of vegetation. As soon as the first pods are ripe, the plants are uprooted, carried in bundles to the threshing-floor, and allowed to dry before the seed is beaten out.

In the Middle East this crop seems to attract most attention in

Palestine. It is sown in winter, and it can remain growing till the drier weather after April is well established. The pods are 5 cm. long and the grey seeds 4–5 mm. in diameter. It is specially used in east Jordan lands both for cutting green as fodder and as ripe grain, the latter being chiefly used as cattle food. In Turkey it is rarely grown in pure culture. In fact, it is regarded as a noxious weed in many parts of the country, infesting fields of chickpeas and to a less extent fields of wheat or barley. In Cyprus its cultivation seems to be dying out.

Another species of Lathyrus is the so-called Cyprus vetch (*Lathyrus ochrus*). In Cyprus itself the grain is used for both human and animal consumption, in the latter case usually as a thick soup. It grows as a prostrate trailing crop with stems 12–18 in. long. Although it suits certain classes of soil and gives variety to the diet, it has no special advantages over other legumes. It is also cultivated in Turkey, especially in western Anatolia near Izmir, and has been introduced into Palestine where it can be sown up to December at Rehovoth, but not later [16].

Another crop found in all countries but not prominent in any of them is the lupin. The various varieties of this species form a winter crop in Palestine, and are there used for animal food. The grain is eaten by poor people, but it is used chiefly for goats. In Egypt the crop is an old one and was known to the ancient Egyptians. It is grown chiefly in Upper Egypt on sandy river-banks and the edges of canals and ponds where other things would not grow. It is there sown generally for grain and is largely used for human food. It grows best in dry sands and sandy loams, but they must not be wet. Sown in October or November, it receives no manure, and no waterings are usually given, but it yields about 20 bu. per acre. The seed has a bitter taste which, however, is removed by soaking and boiling in water. In Turkey the lupin is very rarely grown, and is likely to remain so, owing to the prevalence of calcareous soils.

It is curious to find, on the edge of the richest pulse area in the world, that some of the Indian pulses have not penetrated into the Middle East. Thus, one of the most extensively grown pulses in India, the pigeon pea (*Cajanus indicus*), is nowhere more than a curiosity, though it would seem to have a possible future in many parts of the area. J. B. Knight [11] has suggested that it might be usefully introduced into Persia.

The various types of Phaseolus, grown very extensively in India, are almost lacking in our area, and some of them showed little or no promise when tried in Egypt [15].

Dolichos lablab and *D. biflorus*, the hyacinth bean and the horse gram respectively, though very widely cultivated in India have no place in the Middle East. Perhaps they have little future there, but in my view Cyamopsis, the Indian *guvar*, would be of considerable use in some of our countries. It is suitable for light land and grows in the hotter part of the year. In Sind it is planted in June and reaped in the early part of the cold weather. Its upright character is valuable and it needs very little irrigation-water.

REFERENCES

1. A. D. HALL, Improvement of Native Agriculture. London, 1936.
2. J. ELAZARI-VOLCANI, The Fellah's Farm. Tel-aviv, 1930.
3. N. I. VAVILOV, Studies in the Origin of Cultivated Plants. Leningrad, 1926.
4. M. G. POPOV, Bull. Appl. Botany, 1928–9, **21**. (Leningrad.)
5. P. ZUKHOVSKY, La Turquie agricole. Moscow, 1933.
6. D. L. SAHASRABUDDHE, The Acid Secretion of the Gram Plant. Agric. Res. Inst., Pusa, India, 1915, Bull. No. 45.
7. N. I. VAVILOV and D. D. BUKINICH, Agricultural Afghanistan. Leningrad, 1929.
8. R. LITTLEJOHN, Private communication, 1946.
9. G. DALMAN, Arbeit und Sitte in Palästina. 1932, **2**.
10. L. A. P. ANDERSON, A. HOWARD, and J. L. SIMONSEN, Indian J. Med. Res., 1925, **12**, 613.
11. J. B. KNIGHT, Report on Agricultural Conditions in Persia (unpublished).
12. E. BAROULINA, The Lentils of the U.S.S.R. and of other Countries, Bull. Appl. Bot., 1930, Suppl. No. 40. (On Russian with English summary.)
13. G. P. FOADEN and F. FLETCHER, Text-book of Egyptian Agriculture, vol. 2. Cairo, 1910.
14. A. F. EL-HELALY, Min. of Agric. Egypt, 1939, Bull. No. 201.
15. R. H. FORBES, Sultan. Agric. Soc., 1923, Bull. No. 10.
16. S. HURWITZ, Rehovoth Expt. Stat., 1940, Bull. No. 26.
17. L. I. GOVOROV, Bull. Appl. Bot., 1928, **19**.

(Received July 17, 1947)

LIMING PROBLEMS ON LIGHT SOILS IN THE NETHERLANDS

O. DE VRIES AND P. BRUIN
(*Landbouwproefstation en Bodemkundig Instituut* T.N.O., *Groningen, Netherlands*)

THE lime status of the soil is of importance for all crops and on all types of soil; it requires special attention and care on light soils, i.e. sandy soils, and peat-sand mixtures called 'moor-colonial' or reclaimed moorland soils, which form a large part of the arable land in the Netherlands. The pH of these soils has to be adjusted within narrow limits—say, within 0·5—to ensure good and reliable yields. pH-determinations form an integral part of soil investigations in these regions; extensive pH surveys have been made and others are in hand.

When liming the soil, the aim is not—as it is with manures like nitrogen, potash, and, to a large extent, phosphate—to provide for the requirements of the next crop; one aims at reaching, either in one dressing or in the course of a few years, an optimal lime status. Soil analysis therefore has to determine two properties: the actual state of the soil (for which purpose the pH in an aqueous suspension is used in our country), and the amount of lime necessary to reach another (the desired) state. For the latter purpose we determine the 'lime factor' of the soil, by which is meant the amount of lime, expressed as kilograms of $CaCO_3$ per hectare, needed to increase the pH by 0·1 in a layer 10 cm. deep, when all the lime is taken up by the humus.

For determining the lime factor of the soil the following method has been adopted, after several trials and extensive preparatory investigations [1]. Twenty grammes of air-dry soil are mixed carefully with 400 mg. of fine, precipitated calcium carbonate in a 150–200 c.c. wide-necked flask; the mixture is stirred to a paste with some water, left standing overnight at room-temperature, stirred again, and then dried in an oven at about 100° C. The bicarbonate formed is thereby decomposed and the CO_2 removed. The unchanged carbonate is then determined with hydrochloric acid, using the Scheibler method, the volume of CO_2 being compared with the amount evolved from a known quantity of pure calcium carbonate at the same room-temperature and atmospheric pressure. This gives the amount of base, in milli-equivalents per 100 gm. of soil [2], necessary to saturate the clay and the humus in contact with a surplus of calcium carbonate under the chosen conditions. From this T-S figure, and from the S-figure, determined by treating the soil with 0·1 N. hydrochloric acid, the base saturation T (in milli-equivalents per 100 gm. soil) and the degree of base saturation V are calculated. For acid sandy and peaty soils (pH $<$ 6) 0·1 in pH corresponds with 2 per cent. in V. The lime factor [1] is then found from the formula: lime factor $=$ 10 T $\times$ volume weight of soil.

It was found that this method of determining the lime requirement, based on conditions naturally existent in the soil (saturation in moist condition in contact with $CaCO_3$) gives on the average (when seasonal variations are eliminated) satisfactory results, provided that the calculated amount of lime can be properly and evenly mixed with the soil, and there is no loss by leaching. In ordinary cases, e.g. in experiments on

small plots or in tanks without bottoms, as well as in experimental fields and agricultural practice, the desired pH is often not reached and rather large deficiencies, amounting to 0·5 pH or more, may occur.

Many data about differences between laboratory measurements and results in field experiments are to be found in the literature. Christensen and Tovborg Jensen called the ratio of these two the 'liming factor' [3] and, using their $Ca(OH)_2$ titration method [4], found a value of about 3 for this factor on different types of soil. Tovborg Jensen found the same factor for a soil with a very high humus-content, whilst in the surface-layer of this soil only a third of the lime applied could be recovered as exchangeable CaO and only traces of $CaCO_3$ were left [5]. He hinted at great losses by leaching. In a later publication losses of lime from the surface-layer of the soil, some years after liming, were calculated from the results of some experimental plots, based upon extractions with 20 per cent. HCl [6]. E. M. Crowther made the hypothesis of losses by leaching more plausible by showing the effect of liming upon deep layers, up to 36 in. below the soil surface [7].

We have also made extensive investigations to clear up these discrepancies between laboratory and field results, and found the following to be the principal causes:

(*a*) Oscillations in pH in the field, generally termed seasonal variations;

(*b*) Losses of lime by leaching and drainage in the first months after liming, which on light soils were found to be much larger than hitherto supposed.

Seasonal Variations in the pH of the Soil

These have been studied from many sides [8]. In a communication from one of us [9], different causes of this phenomenon have been discussed; we shall not go fully into this subject here but consider only the nature and the magnitude of the variations in pH as determined in 1 : 5 aqueous suspension measured with the quinhydrone electrode.

Fig. 1 illustrates the nature of this phenomenon by figures obtained on two plots of an experimental field which had been manured during a series of years, the one by sodium nitrate and basic slag, the other by sulphate of ammonia and superphosphate, whilst both received the same potassium dressing.

As Fig. 1 shows, pH is raised by the one, lowered by the other type of manure; but it shows oscillations around the general trend, and these oscillations have in the main the same direction for both types of manure. It is possible to calculate the standard error for these deviations from the distances of the points to the average trend. Using the formula

$$\sigma = \sqrt{\frac{\sum d^2}{n}},$$

we found from an experimental material obtained from 29 experimental fields and relating to 942 observations, a standard error of 0·17 pH. The error of sampling on these experimental plots (size $\frac{1}{2}$–1 are; 12

borings per plot), and the error of analysis when analysing in duplicate, were known to be 0·065 pH. The total standard error of a pH figure for a soil sample from an experimental field is therefore 0·18 pH on the average [10]. This means that, when comparing pH figures for one plot, found in two yearly samples, in 5 per cent. of the number of cases a difference greater than 0·5 pH, and in 25 per cent. of the cases a difference greater than 0·3 pH may be ascribed to the unavoidable errors and not to the effect of lime or other factors. This is a rather large figure.

When studying the changes in pH brought about by a certain amount of lime, it is therefore better to put the question in this way: how far is

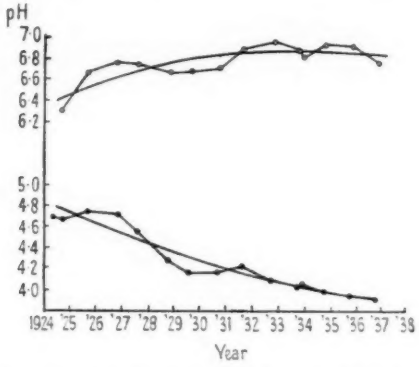


FIG. 1. Example of yearly variations in pH of the soil. Samples taken after the harvest of each year. Every point is the average of the figures of four parallel plots. The smooth lines indicate the average trend, eliminating the yearly variations: above for alkaline manure (nitrate of soda and basic slag), below for an acid combination (sulphate of ammonia and superphosphate).

it possible to raise, by liming, the pH of a plot by a given amount above the pH of an unlimed plot in the same field? Some of our investigations of this kind are described in the following pages.

Losses of Lime by Leaching and Drainage shortly after Liming the Soil

We estimated the losses of lime in our experiments by determining the base-content by one extraction with 0·1 N. hydrochloric acid (in the ratio of 20 liquid to 1 soil) and titrating the free acid, using phenolphthalein as indicator. A comparison between the figures for the limed and the unlimed plot shows the percentage of the added lime that has been retained. When one also determines the amount of unchanged $CaCO_3$, it is possible to calculate the amount of the added lime that was bound by the humus.

It was in the first place necessary to determine how far the above-described extraction with hydrochloric acid gives a correct indication of the amount of lime that had been added. In experiments with 15 different types of soil, to which different amounts of chemically pure calcium carbonate had been added in a porcelain dish, so that no losses

could occur, we found practically complete recovery (on the average 97 per cent.). Furthermore, it was found that up to pH 6·5 the lime was practically all bound by the humus, whilst with larger quantities of added calcium carbonate part remained unchanged.

Similar figures were obtained in a laboratory experiment with a soil to which increasing amounts of lime had been added; the same sandy soil (humus 14 per cent., pH 4·3) was used in a further experiment (VPr 19) on small plots (800 × 80 cm.) in the open, separated by wooden partitions. A layer of 20 to 25 cm. of the sandy soil was placed on a layer of coarse white subsoil sand, infertile and poor in humus. To this upper layer different amounts of a local marl (98 per cent. $CaCO_3$ with about 80 per cent. passing a 0·17 mm. sieve), were added on July 29, 1930. The pH was found to be:

	Amount of lime added in mg. equiv. per 100 gm. soil			
	0	*6·1*	*10·2*	*12·3*
Nov. 7, 1930 . .	4·7	5·1	5·7	5·9
Oct. 1, 1931 . .	4·2	4·8	5·35	5·5

The frames were planted with spinach on Aug. 15, 1930, and in 1931 different legumes were grown. The loss of lime was 26 per cent. on the average in Nov. 1930, and 32 per cent. in Oct. 1931. These figures are so much larger than the errors of determination in the laboratory experiments that the losses are unquestionable. It may be remarked that all of the lime had already been bound by the humus on the first sampling date (Nov. 1930, 3 months after liming).

On Nov. 17, 1931, further portions of lime (3·0, 6·5, and 8·9 mg. equiv. per 100 gm.) were added, this time in the form of powdery slaked lime, which was stirred as well as possible into the upper layer. They gave, on Feb. 24, 1932, a pH of 4·3 (unlimed), 5·4, 6·2, and 6·7 respectively. The loss of lime was 14 per cent. after this second addition.

In the above experiments the percentage loss by leaching is nearly the same, i.e. is independent of the amount of added lime.

A loss of 26 per cent. in 3 months means for the largest application of marl used in this experiment a loss of 3,000 kg. $CaCO_3$ per hectare. The questions arise: in which form is this large amount of lime removed and is it possible that this amount leaves the top soil layer in the form of bicarbonate? The reaction between humus and added $CaCO_3$ produces CO_2, which may convert part of the calcium carbonate into calcium bicarbonate; at low concentrations of $Ca(HCO_3)_2$ practically only one gram-molecule of CO_2 is needed to convert one gram-molecule of $CaCO_3$ into bicarbonate, but at higher concentrations the amount of free CO_2, that must be present, is larger. The data of Schlösing [11] and Kurris [12] show that, at a CO_2-pressure of about one-third of one atmosphere, twice as much CO_2 is needed as the quantity necessary for the formation of bicarbonate from carbonate.

If the CO_2-pressure from the reaction between humus and $CaCO_3$ reaches the value of one-third of an atmosphere, the amount of CO_2

evolved from three-quarters of the calcium carbonate present would be necessary to maintain one-quarter in the form of bicarbonate. In our case the loss after 3 months is 26 per cent. of the amount added.

The total rainfall from July 29 till Nov. 7, 1930, measured in the garden of our Experimental Station, was 370 mm. or 3,700,000 litres of water per hectare. As one litre of water at an assumed CO_2-pressure of one-third atmosphere can dissolve at the most 725 mg. of calcium carbonate, this amount of water would be able to remove in solution at total saturation 2,700 kg. of calcium carbonate. The actual figure would, of course, be much smaller (due to evaporation of rain-water[1], only partial saturation by calcium bicarbonate, &c.), so that the loss of 3,000 kg. calcium carbonate, calculated from the analytical figures in the example given above, could, in the assumed circumstances, only have taken place in part in the form of bicarbonate dissolved in the drainage water; the rest should have left the upper layer in another form.

At higher CO_2-pressures than were assumed above, the solubility of calcium carbonate is greater. In such circumstances, however, part of the carbon dioxide must have been produced by microbiological destruction of humus. It is clear that analysis of the drainage water should supply more accurate figures, particularly for the anions. Some of the kations will undoubtedly occur in the drainage water in the form of sulphate or nitrate derived from mineral salts added as a manure (the spinach was manured on Aug. 9, 1930, with sulphate of ammonia, superphosphate, and potassium magnesium sulphate at the rates of 200 kg. N, 100 kg. P_2O_5, and 200 kg. K_2O per hectare respectively), or formed by bacterial decomposition of humus and plant residues, &c.

A further possibility is the removal of calcium carbonate in a purely mechanical way, such as was assumed by de Vries and Hetterschij for part of the displacement of phosphates in a sandy soil [13].

The figures of the above experiment show that the loss of calcium carbonate is much larger in the first 3 months than in the following 11 months, 26 as against 6 per cent. This may imply a larger leakage when unchanged calcium carbonate is present than when the calcium is taken up by humus in the latter period; but it seems probable that the CO_2 developed during the first months by the reaction between humus and carbonate is the factor mainly responsible. In this connexion it may be pointed out that the second amount of lime, applied on Nov. 17, 1931, underwent a loss of only 14 per cent. in the following 3 months, and this loss is much lower than that of calcium carbonate from the first amount of lime, applied on July 29, 1930. This fact gives an indication of the possible influence of the type of lime on the losses by drainage shortly after liming the soil. It should be noted, however, that the rainfall in the 3 months after the second application was much lower than that after the first application (157 mm. and 370 mm. respectively).

[1] In a lysimeter experiment made at our Institute, J. G. Maschhaupt used a layer of untilled light clay soil 1 m. thick. He found the average drainage loss to be 50 per cent. of the rainfall in the months August–October 1934–7. In our experiments the soil layer was 20 to 25 cm. thick, so that a somewhat greater part of the rain-water will have passed the limed layer of the soil and brought calcium carbonate from it into solution.

To study this point further, data derived from an experiment in Mitscherlich pots, containing the same humic sandy soil as above, were used to investigate the velocity of the reaction between humus and different forms of liming materials. The pots were set up in the garden and left unplanted. The results, obtained at different times after applying the lime, are given in Fig. 2. The figures for different amounts of lime (6·3, 12·7, and 21·1 mg. equiv. per 100 gm. soil, respectively) have been averaged, because the percentage loss is the same for smaller and

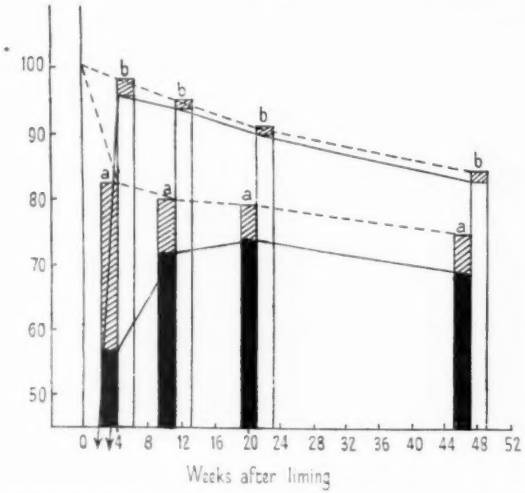


FIG. 2. Percentage amounts of calcium carbonate recovered from the soil (black columns for the calcium bound to the humus and hatched columns for the unchanged carbonate) at different dates after liming, and when using marl (*a*) and slaked lime (*b*) respectively. For marl, each point is the average from nine pots with three different quantities; for slaked lime from three. The full lines give the changes in percentage of lime taken up by the humus, the interrupted lines the total percentage of lime still present in the soil.

larger dressings. It will be seen that the amount recovered after different intervals (given by total height of the columns) decreases much more quickly for the marl than for the slaked lime. After 4 weeks about 20 per cent. of the lime given as marl had disappeared, whilst the soil to which slaked lime had been applied showed practically no loss; after about a year the losses were 25 and 15 per cent. respectively. It is very remarkable how quickly the loss takes place in the marled pots; later, the losses are much slower. We observed a similar course in other pot experiments with marl. From these observations it appears probable that the large amount of CO_2 produced by the reaction between humus and calcium carbonate plays an important role.

Fig. 2 further shows that the amount bound to the humus is lower at first for the marled pots than for those with slaked lime. The reaction between $CaCO_3$ and acid humus proceeds gradually and reaches a

maximum after 20 weeks, whilst with slaked lime nearly all the lime is bound in 4 days, and afterwards the amount of exchangeable calcium decreases. (The calcium hydroxide, not bound by humus, quickly changes into calcium carbonate and can be determined as such.)

It may be emphasized that the above conclusions about rate of loss and the different behaviours of marl and slaked lime, drawn from a pot and a small plot experiment, should not be generalized, and need not hold for the reactions in the field. In our field observations we sometimes found the losses of lime to be very large in the first year and

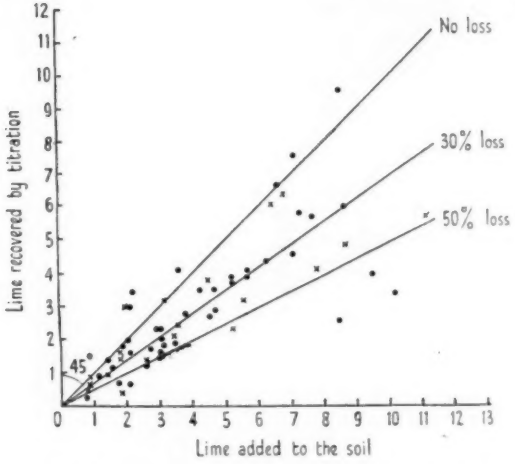


FIG. 3. Amounts of lime recovered after about a year, against the amount applied, for 60 plots on 25 different experimental fields on various types of soil and under varying local conditions. Average loss about 30%, average for extreme cases about 50%. Dots: limed with marl; crosses: slaked lime.

smaller in later years, but in other cases the losses in lime are relatively small and sometimes continued for a period of years. It may also be said that in general the application of lime as hydroxide does not cause smaller losses than the carbonate.

We investigated the results of 25 field experiments with lime, including in all 60 treatments each on 2 to 5 parallel plots. The experiments were carried out in different parts of the country, on different types of soil, and under different local circumstances. It is self-evident that the figures for loss of lime from the top soil will show a larger experimental error for the field data than for those from experiments in pots or bottomless frames. In pots the layer of top soil is measured accurately or even weighed, whilst in the field one has a roughly estimated thickness of the top layer, and an uncertain volume-weight, even if one takes volume-weight and thickness always for the settled top soil as it is after the harvest in a grain stubble. Nevertheless, when studying a large number of such cases, one gets an interesting picture (Fig. 3) giving the relation

between amount of $CaCO_3$ added and amount recovered about a year after the application, investigated by the method of analysis described above and always in comparison with the unlimed plot. The dots relate to marl and the crosses to slaked lime: a difference in behaviour between the two is not apparent. There are certain cases falling in the neighbourhood of the 45°-line, in which therefore practically no loss of lime had occurred. The average of all points is roughly represented by the line for 30 per cent. loss. We have also drawn a line for 50 per cent. loss, which just about averages the extreme cases. The average loss on these

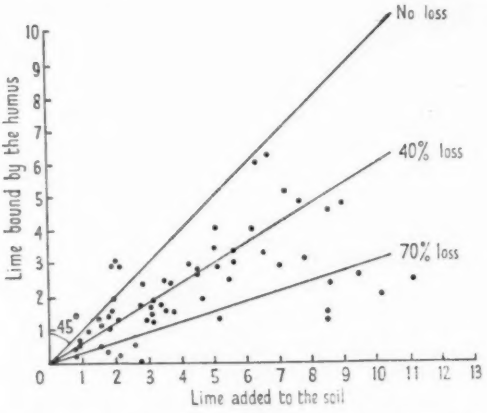


FIG. 4. Amount of lime (in milli-equivalents per 100 gm. of soil) bound to the humus in about a year, against amount of lime applied, for the same experimental material as in Fig. 3. Average of lime not bound about 40%, in extreme cases about 70%.

experimental fields was about 30 per cent. of the added lime in the course of a year.

Fig. 4 relating to the same experimental material as Fig. 3, gives the amount bound to the humus after a year, compared with the amount applied. The average figure is about 40 per cent.; the lower figures indicate a loss of about 70 per cent. By far the larger part of the lime lost must have disappeared into the lower soil layers. It may be safely assumed that in a year a maximal degree of binding by the humus has been reached. When 40 per cent. of the applied lime has not been bound by the humus in the course of a year, this means that one has to give about 1·7 times the amount calculated, to reach finally the desired lime status or pH. When there is a loss of 70 per cent., one has to give roughly three times the calculated amount and has therefore to use a 'liming factor' of 3. The conclusion from Fig. 4 is that there is no universal 'liming factor' for all types of soil and conditions: on the contrary, circumstances are found to be extremely divergent and different factors would have to be used in different cases. Moreover, it will be clear that the use of such a high factor as 3 would be very dangerous and uneconomic in the case of humic sandy soils; they are very pervious to water, and the losses by leaching

would probably be very large when such large amounts of lime were added, and especially so when the pH has to be raised a considerable amount and one has to apply correspondingly large amounts of lime. Moreover, such a very large amount of lime may temporarily cause a very high and perhaps harmful pH, leading to deficiency and other diseases. It is therefore better in practice to choose not too great an amount of lime, to determine after a suitable lapse of time the pH actually reached, and then to add a further amount of lime to reach the desired state.

Conclusions

It will be clear from the above that, even though the laboratory method gives reliable and sufficiently accurate indications regarding the amount of lime that has to be bound by the humus to reach the desired rise in pH, there remains much uncertainty as to how much of this lime will actually form a calcium-humus compound. Moreover, the seasonal variations in pH may be so capricious that there may be considerable uncertainty as to the effect that has been reached. The behaviour and effect of lime may vary greatly with soil conditions, and the uncertainties in the determination of the lime status make it is very difficult to predict the exact result of a given application of lime, or to prescribe the dose necessary for obtaining a certain effect. In liming prescriptions for experimental fields we generally add an extra allowance of one-fourth to one-third of the amount of lime calculated from the lime factor and the pH to be reached, to compensate for the lime that will rapidly disappear from the top soil or remain unused in the form of coarse and inactive particles. For actual practice, advice on amounts of lime to be applied can only be very approximate, more in the manner of a rule of conduct than as a definite indication. The directions have already been given above: they prescribe a moderate dose, to be followed by another dose after about a year, preferably calculated according to the effect actually reached by the first one.

REFERENCES

1. O. DE VRIES, Bodenk. u. Pflz. ern., 1938, **54/55,** 309.
2. P. BRUIN, Rec. d. Trav. Chim. d. Pays-Bas, 1936, **55,** 192.
3. H. R. CHRISTENSEN and S. TOVBORG JENSEN, Int. Soc. Soil Sci., Trans. Sect. Ctee, 1926, A, p. 94.
4. S. TOVBORG JENSEN, Int. Mitt. f. Bodenk., 1924, **14,** 112.
5. —— Int. Soc. Soil Sci., Trans. Sect. Ctee., 1929, A, p. 47.
6. —— Arch. f. Pflanzenbau, 1933, **10,** 72.
7. E. M. CROWTHER, J. Agric. Sci., 1925, **15,** 232.
8. R. CHAMINADE, Ann. Agron., 1933, **3,** 799.
9. P. BRUIN, Chem. Weekblad, 1935, **32,** 218.
10. —— Versl. v. Landbk. Ond., 1938, **44,** 623–92.
11. Th. SCHLÖSING, Compt. rend. Acad. Sci., Paris, 75 (1872), 70 and 74 (1872), 1552.
12. F. J. J. H. KURRIS, Dissertation, Delft, 1930.
13. O. DE VRIES and C. W. G. HETTERSCHIJ, Rijkslandb. Proefstat. Groningen, 1936, p. 56; Bodenk. u. Pflz. ern., 1937, **2,** 178–86; (with F. v. d. Paauw.) Landbouwk. Tijdschr., 1937, **49,** 768–807.

(*Received January 20, 1947*)

INDEX

Alfalfa, breeding for self-tripping character to improve seed-yield, 82–8; methods of selecting, 82–3; seed-yields, 82–7; yields of single crosses, 83–6, of synthetic strains, 86–7.
Armstrong, J. M., and Stevenson, T. M., effects of continuous line selection in Triticum-Agropyron hybrids, 51–64.

Blue tick, the arsenic-resistant, in South Africa, 42–7.
Bolton, J. L., *see* Stevenson, T. M.
Boyns, B. M., Sudanese cattle as milk-producers, 27–41.
Broadfoot, Jane, preliminary experiments on the protection of cut sets of potato from infection with Penicillium, 227–36.
Bruin, P., *see* Vries, O. de.

Cattle, artificial insemination in, 149–59; breeding policy, 155–8; organization in England, 150–5; technical developments and research, 158–9.
— Indian, in the United States of America, 213–15; hybrids of Brahman (Zebu), English, and native cattle, 213–15; influence of Zebu blood on range cattle, 215; Palmetta palm and other herbage, 214–15.
— infestations with arsenic-resistant blue tick, 42–50.
— pedigree, age-distribution of, 119–31; age in relation to milk-recording and tuberculin-testing, &c., 126–28; age-composition of Red Poll female population, 120–4; age-distribution of Ayrshire and Jersey cows, 125–6; comparison of age-distributions from herd-lists and heifer registrations, 124–5, replacements, 128–30.
— Sudanese, as milk-producers, 27–41; cattle of the Sudan, 27–8; early work on improvement, 28–9; foundation of Shambat herd, 29–30; lactation results, 30–4; methods for improving native stock, 34–40.
Coffee, arabica, yields, preparation out-turns, and quality in. I. Yields, 96–106; biennial bearing, 101–2; climate, soil, seed, 96–7; combined seasons' yields, 103–5; comparison of estate- and plot-yields, 98–9; effect of shade on yields, 102–3; methods used in crop-recording, plot-selection, &c., 97–8; variation in yields, 99–101. II. Preparation out-turns and quality, 167–76; methods, 167–9; quality, 172–4; variation in grades, 171, in out-turn ratios, 169–71, in size and weight of beans, 171–2, in quality, 172–4.
— robusta, in Uganda, 65–81; breeding, 74–9; development, 66–8; historical, 65–6; prospects, 79–80; selection, 68–73; training, 73–4.
Confounding arrangements, construction of, 107–12; factors at two levels, 107–9, three levels, 109–11, more than three levels, 111–12.

Davis, A. G., lucerne growing, 113–18.
Dent, J. M., soil problems of empoldered rice lands in Sierra Leone, 206–12.
Diseases and pests, ecto-parasitic infestations of farm stock in South Africa, 42–50.
Donald, H. P., age-distribution of pedigree cattle and factors affecting it, 119–31.

Edwards, J., artificial insemination in cattle, 149–59.
El Itriby, A. A., *see* Donald, H. P.

Fertilizers, inorganic, compared with compost on South African pastures, 189–94; harvesting methods, 190–1; recovery of N and P_2O_5, 192–3; treatments, 189–90; types of pasture, 190; yields, 191–2.
Finney, D. J., construction of confounding arrangements, 107–12.
Foodstuffs, mineral composition of mine-compound, in Northern Rhodesia, 89–95; experimental, 89–90; results, 90–4.

'Gammexane', use of, against arsenic-resistant blue tick in South Africa, 42–50; dipping tests and dip-washes, 44–5; spraying test, 43; trials, object and results of, 45–7.
Glover, J., environment and the growth of the potato in tropical East Africa, 9–26.
Golledge, A., *see* Young, R. S.

Hallsworth, E. G., factors affecting the ascorbic-acid content of tomatoes in New South Wales, 132–47.
Hawkes, J. G., photoperiodic reactions of potato bolters, 216–26.

Insemination, artificial, in cattle, 149–59.

Lathbury, R. J., development of wheat varieties in Kenya, 177–88.
Lewis, V. M., *see* Hallsworth, E. G.
Liming problems on Netherland light soils, 260–8; lime factor, determination of, 260–1; lime losses by leaching and drainage, 262–8; seasonal variations in soil pH, 261–2.
Littlejohn, L. J. S., experiments with potatoes in Cyprus, 195–205.
Lucerne growing, 113–18; companion plants and seed-rates, 113–17; management, 117; 'strain', 117.

Mann, H. H., pulse grain crops in the Middle East, 249–59.
Meredith, D., comparison of inorganic fertilizers and compost on natural pastures in South Africa, 189–94.
Moorland plants, ash components of, 237–48; experimental technique, 237–8; *Eriophorum vaginatum*, 244–5, 246; *Juncus squarrosus*, 243–4; *Molinia coerulea*, 238–9; *Nardus stricta*, 242–3; *Scirpus caespitosus*, 239–40; *Vaccinium myrtillus*, 240–2.

Plank, J. E. van der, some climatic factors determining high yields of potatoes, 1–8.
Potato bolters, photoperiodic reactions of, 216–26; materials and methods, 217; observations on flowering, 218–19; height of plants, 217–18, maturity, 219, stolon length and number, 222–4; tuber length and number, 219–21; summaries, 224, 225–6.
— environment and growth in tropical East Africa, 9–26; environmental factors, 11–17; experimental plots and technique, 9–11; field observations, 18–20; growth and yield measurements, 17.
— protection of cut sets from infection with Penicillium, 227–36; laboratory tests, 228–31; methods used, 227–8; planting trials, 231–2; transport trials, 232–4.
Potatoes, climatic factors determining high yields of. II. At low latitudes and high altitudes, 1–8; length of day, 3–5; poor seed, 2; unsuitable varieties, 2–3. Summary of Pts. I and II, 7–8.
— experiments with, in Cyprus, 195–205; dormancy, breaking of, 202–4; rose-ends, trials with, 198–202; seed certification, 204–5; variety trials, 196–8; yield as function of age of seed, 195.
Pulse grain crops in the Middle East, 249–59; beans, 254–6; chickpeas, 250–1; cowpeas, 256–7; *Lathyrus ochrus*, 258; *Lathyrus sativus*, 257–8; lentils, 253–4; lupins, 258; peas, 256; vetches, 251–3.

Rice lands, soil problems of empoldered, in Sierra Leone, 206–12; soil analyses, 210; toxicity associated with common salt, 211, iron salts, 207 sqq., mangrove and other vegetation, 208–12, peaty matter, 208 sqq.

Stevenson, T. M., evaluation of the self-tripping character in breeding for improved seed-yield in alfalfa, 82–8.

Tea, effect of cultivation on growth of young, 160–6; cultivation methods, 160–2; growth of plants, 162–3, of roots, 162–5, 166.
Thomas, A. S., cultivation and selection of robusta coffee in Uganda, 65–81.
Thomas, Brynmor; ash components of some moorland plants, 237–49.
Thorburn, J. A., control of ecto-parasitic infestations of farm stock with 'Gammexane', with special reference to the arsenic-resistant blue tick, 42–50.
Thorold, C. A., study of yields, preparation out-turns, and quality in arabica coffee, 96–106, 167–76.
Tomatoes, ascorbic-acid content of, in New South Wales, 132–47; climatic data, 132–3; effects of maturity of bush, 138–9, ripeness, 134, storage, 134; relation between content and leafiness and surface area, 136, 142–4, locality, 141–2, size and weight of fruit, times of picking and sowing, 139, 140; varietal differences, 140–4.
Trinder, N., *see* Thomas, Brynmor.
Triticum–Agropyron hybrids, effects of continuous line-selection in, 51–64; chemical composition of hybrids, 54–6; emergence of grasses, T–A hybrids, and wheat sown at varying depth, 53–4; perennialism, 56–8; variability in advanced generations, 58–63.
Tubbs, F. R., effect of cultivation on growth of young tea, 160–6.

Vries, O. de, liming problems on light soils in the Netherlands, 260–8.

Ware, F., Indian cattle in the United States of America, 213–15.
Wheat, development of varieties in Kenya, 177–88; acreage, prices, yields, 178–9, 187; baking quality, 179; breeding for rust-resistance, 181; early history, 177; new hybrids, 181–5; selections and introduced varieties, 185–6; stem rust and yellow rust, 179–80.

Young, R. S., mineral composition of mine-compound foodstuffs in Northern Rhodesia, 89–95.

CORRIGENDA

Vol. XV, No. 57, pp. 9–26. Fig. 1, *delete* present title and *insert* 'The climate of M'.
— Fig. 2, *for* 'K 1' *read* 'K 2'. *Delete* '21° C.', and after '24° C.' *add* '27° C. 0–0 and 30° C. x–x'.
— Fig. 3, *delete* present title and *insert* 'The climate of K 2'.
— Fig. 5, *delete* present title and *insert* 'The climate of K 1'.
— Fig. 6, *for* 'K 2' *read* 'K 1'; *delete* '27° C. 0–0' and 30° C. x–x', and *insert* '21° C. and' before '24° C.'.